



Biomass Program Multi-Year Technical Plan

Office of the Biomass Program

FY 2004 and beyond

Submitted by:

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Golden Field Office

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1 Overview

The Biomass Program is a comprehensive federally funded research, development and deployment effort focused on science and technology that will establish biomass as a significant source of environmentally-sound, sustainable and renewable fuels, heat, power, chemicals and materials. Biomass is unique among all the options for renewable resources. Biomass is the only single resource that by itself can serve as a sustainable supply of all of the following: food, fiber, heat, power, and carbon-based fuels and chemicals.

The Biomass Program is managed by the Office of the Biomass Program (OBP), one of eleven offices responsible for the development of a portfolio of sustainable energy technologies sponsored by the Office of Energy Efficiency and Renewable Energy (EERE) within the U.S. Department of Energy (DOE). The overarching goals of the Biomass Program are to dramatically reduce or even end our dependence on foreign oil, and to create a bioenergy industry within the U.S.

This multi-year technical plan (MYTP) documents the detailed strategies, plans, and activities to be carried-out by the Biomass Program over the next 5+ years to achieve OBP's goals. Much of what's contained in this MYTP, emanated from a 3-day planning session held in May of 2003 and attended by representatives from OBP, five DOE National Labs, the USDA, and representatives of the Golden Field Office of DOE. The National Renewable Energy Lab (NREL), OBP's Federally Funded Research and Development Center (FFRDC) has taken the lead role in compiling this MYTP.

This MYTP is the first edition of any such multi year planning document covering the entire Biomass Program. The Program has and is likely to continue to undergo change as DOE works to maximize the value of its investments in the research. This planning document will be revised annually to document the adaptation of our plans to the changing needs of DOE and the progress of the research and development activities. The true value of this plan is in the process that we've gone through to develop the plan, more so than the final document.

The disciplined thinking that went into this plan helped OBP and NREL identify the strengths and weaknesses of our strategies. In the coming year, we will be working to further improve our strategic plans. This document merely is a snapshot of our most current plan. Annual revisions will allow us to measure our progress on the path toward our goals. And, as long as our planning process consists of a continuum of questioning and reassessing where we are going, it will also document, over time, the changes in direction and new choices necessitated by new information or changes in the external environment.

In simple terms, this MYTP planning process helps us to understand where we want to go in the context of where we have been, and it provides measurable markers along the road to assess our progress. And finally, the plan reflects the limitations of what we can do based on our best understanding of the resources that will be deployed in the Biomass Program by the federal government.

1.1 The Evolution of the Biomass Program

The Biomass Program represents a consolidation of several previously distinct and separately managed programs. What is now known as the Biomass Program includes what had been:

- The Biomass Feedstock Development Program (BFDP),
- The Biofuels Program (BFP),
- The Biopower Program (BPP), and
- Biomass-related elements from research previously sponsored by the Office of Industrial Technologies (OIT).

The BFDP had emphasized research on production, harvesting, and assessment of biomass resources for energy usage. The Biofuels Program was focused on research to produce liquid transportation fuels from biomass, dominated by research on bioethanol (ethanol made from lignocellulosic biomass) with a modest amount of work on Biodiesel (fatty acid esters, a renewable fuel substitute for petroleum diesel made from natural oils.) The Biopower Program was focused on the development of thermochemical processes for the production of heat and power from biomass. Finally, the research sponsored by the Office of Industrial Technologies involved the development of value-added chemicals and materials from biomass.

Figure 1 illustrates the relationship of these previously separate programs after being consolidated into one Biomass Program. The individual program activities are now managed by one office, resulting in a more integrated and concerted effort directed toward generating technology that can flow directly into industry-led partnerships for commercial development. There are five areas of the new Biomass Program that fall into one of two categories: 1) core R&D that emphasizes enabling technology for biorefineries; and, 2) integrated biorefinery development activities that pulls together all the pieces of core technology for a specific commercial biorefinery scenario. As research moves from core R&D to integrated validation and demonstration of biorefinery technology, the lead in the work shifts from the public sector to the private sector.

This organization of the work allows the Program to allocate its federal funding resources toward pre-commercial enabling technology development that can lay the groundwork for future commercialization without competing with or duplicating work in the private sector. The pre-commercial “core program R&D” falls into four main categories:

- Feedstock Interface Core R&D
- Sugar Platform Core R&D
- Thermochemical Platform Core R&D
- Products Core R&D.

Integrated biorefinery development is the fifth area work, which consists of industry-led projects to integrate elements of the core program R&D into commercially viable integrated biorefineries.

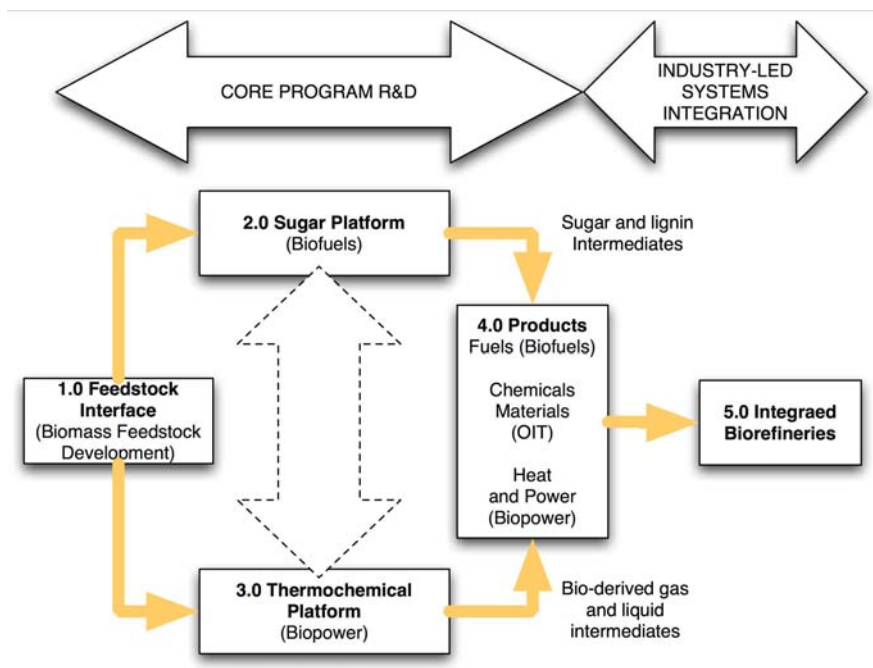


Figure 1 : Schematic of the Workflow for the Biomass Program

1.2 Scope and Approach of the Core R&D Areas

The feedstock research under the previous BFD Program covered a fairly broad range of issues from crop development to optimal energy crop production and harvesting. Under the new Biomass Program, we have opted to focus our resources in the Feedstock Interface area mainly on feedstock harvesting, storage and transportation technology as it relates to the technology employed to convert biomass into energy and products. The broader issues of crop development, crop production and management are now the domain of the U.S. Department of Agriculture, an organization with the appropriate set of skills and resources to address biomass production in a comprehensive manner. Within OBP, emphasis is now placed on developing a harvesting, storage, and transportation technology that will reduce the cost of sustainably delivering biomass to a biorefinery, and on ensuring an effective coordination between DOE and USDA biomass research efforts.

Research under the previous Biofuels Program spanned the entire gamut of technology needed to convert lignocellulosic biomass to ethanol and a lignin residue (a byproduct that could be used to produce other fuels, chemicals or power.) Under the new Biomass Program, that research has been divided into two areas. The focus and goal of the Sugar Platform is to develop cost-effective technology to release sugars from lignocellulosic biomass. The downstream conversion of the sugars (and lignin residue), chemically or biologically, into fuels and chemicals is now the domain of the Products area. Cost effective hydrolysis of biomass to sugars is what we term “enabling technology”. This technology will enable industrial development of a commercial biorefinery to produce fuels, chemicals, and power from lignocellulosic biomass. This represents the single largest area of research among the DOE Labs.

Research under the previous Biopower Program was focused entirely on producing low-cost electrical power from biomass. The new Thermochemical Platform represents a major shift and refocusing of our research at the DOE Labs in this area. The focus and goal of the Thermochemical Platform is to develop cost-effective technology to thermochemically convert lignocellulosic biomass into gas and liquid intermediates that can serve as either fuels or intermediates for fuel and chemical product opportunities.

The research in the Feedstock Interface area and in both of these “conversion” platforms, Sugar Platform and Thermochemical Platform, is focused on pre-commercial enabling technology to reduce the cost of making intermediate building blocks from biomass. Analysis has shown that the cost of producing these intermediates alone represents a formidable barrier to the profitability of envisioned biorefineries. The closer the research moves to addressing specific needs of specific products and specific biorefinery applications, the more likely it is that the Program would cross the line into commercial development activities. These later activities are best done by industry. By focusing on the upstream barriers, the Biomass Program can use its resources to advance the development of commercial biorefineries without interfering in the competitive arena of product development where industry should take the lead.

At the time this MYTP was written, OBP’s strategies in the Products area were still being formulated. Product initiatives must be market driven, with specific well-defined products and markets. Products research will be needed to address the utilization of all the intermediates and byproducts produced by the technology in the conversion platforms in a sustainable manner. As described later in this document (section 2.4), we envision the majority of research in this area will be lead by industry. DOE will cost share research in this area, and DOE Lab resources would be available to support private industry. The second and smaller component of the research in the Products area will be the development of crosscutting technologies that may be of value to enabling more than one specific product or biorefinery application. Here, the focus will be on enabling biological, chemical, and or physical processing steps and process development, rather than on any specific product development efforts.

1.3 Why a biorefinery?

The integrated biorefinery is the conceptual framework that seeks to capitalize on the synergy that results from integrating the previously separate biomass-related programs. The concept of a biorefinery is to convert the complex polymers present in biomass into a number of select products that provide value to society as either fuels, chemicals, or a source of energy. Figure 2 shows a concept of the biorefinery that represents a generic integration of all aspects of biomass conversion technology. In this illustration, there is no limitation to confining the biorefinery concept to one of only a biochemical conversion based biorefinery or a thermochemical conversion based biorefinery. In fact, the combined use of both conversion platforms offer the greatest opportunity for optimizing the conversion of biomass into a variety of different fuels, chemicals and energy products. Not all biorefineries will be this complex, and some may have added complexity.

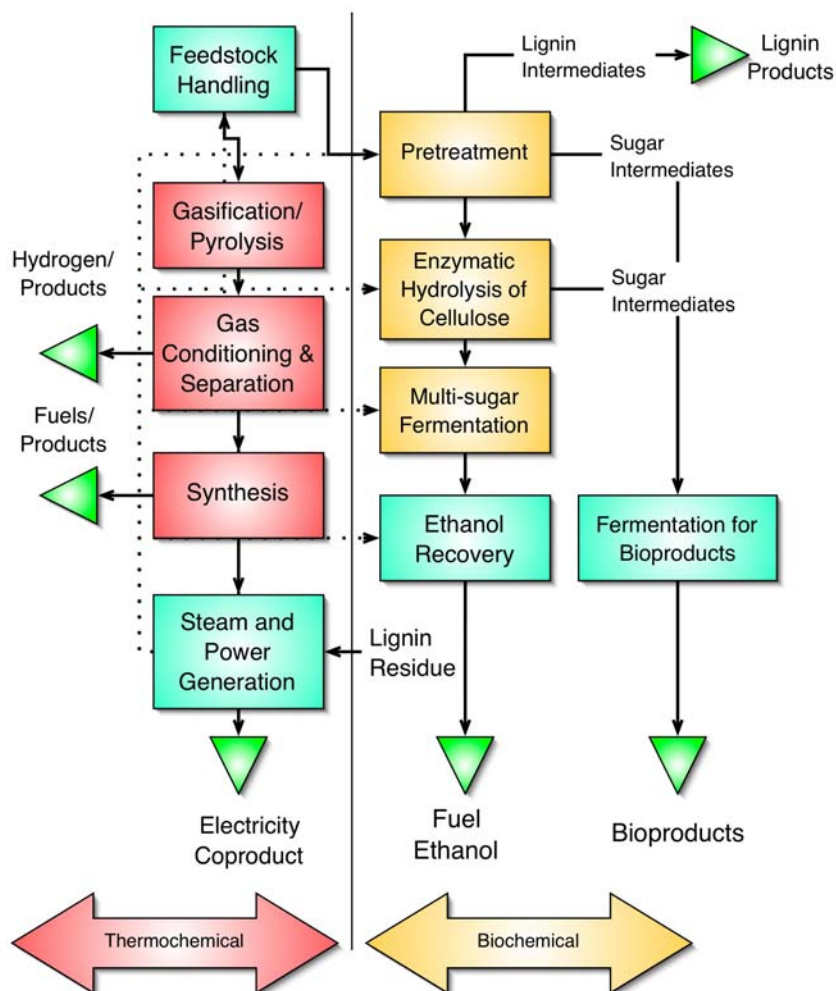


Figure 2: The Ultimate Biorefinery

In many ways, the biorefinery seeks to benefit from the learning's that took place during the evolution of a modern day petroleum refinery. In such an analogy, the reader may recognize the concept below as analogous to a combined use of fluid catalytic cracking, thermal cracking, and/or hydrocracking technology to convert the higher boiling range fractions of crude oil in more useful lower boiling range products. Just as few petroleum refineries utilize all available conversion technologies, biorefineries too will make use of only those technology platforms that are most cost effective for converting a certain type of biomass into a certain collection of desired end products.

In the older biofuels and biopower paradigms, energy production from biomass had to compete head-to-head with very mature technology that utilizes non-renewable sources of feedstock such as coal, petroleum, or natural gas. Moreover, bioproducts as an approach to reducing fossil energy dependence offered only a relatively small impacts vis-à-vis the total demand for energy in the U.S. Combining higher value products with higher volume energy production changes, and employing any combination of conversion technologies has the greatest potential to improve the competitive economy of making fuels, chemical, and power from biomass. Integrated biorefineries offer a way to improve the profitability of biomass processing, and thus become critical toward developing a sustainable source of these necessary commodities from biomass.

1.4 The Timing of Biorefinery Technology

In many parts of the plan, we differentiate technology according to the timeframe within which we see it becoming commercial. We view the portfolio of technology development for the program as falling into three categories:

- Existing biorefineries
- Emerging biorefineries
- Advanced biorefineries

Existing biorefineries are just what one would expect. They are already commercial operations. In the case of the sugar platform, we put today's 2 billion gallon per year corn grain ethanol industry in that category. Examples of existing thermochemical biorefineries include today's pulp and paper mill industry, the growing biomass power industry based primarily on co-firing of biomass and other fossil fuels for the production of heat and power, and the more recent specialty chemical facilities based on fast pyrolysis technology for biomass.

Emerging biorefineries are based on technology that has not yet been proven commercially, but which has a timeline for commercialization that is between five and ten years in length. Emerging technology, in the lexicon of the Biomass Program. It utilizes non traditional sources of biomass, such as agricultural residues and energy crops, as opposed to existing biorefineries that use traditional and/or currently available sources of biomass or waste materials. The technology to cost effectively convert these materials is still in development.

In the case of the sugar platform, we envision emerging biorefineries that are based on enzymatic hydrolysis of biomass to produce sugars and lignin, which can then be converted into a variety of fuels and products. In the case of the thermochemical platform, emerging biorefineries are based on the gasification and/or pyrolysis of biomass. In some cases, the thermochemical platform is an extension of technology that has been proven for coal, but which still requires some development work before the technology can be cost effectively applied to biomass.

The advanced biorefinery is based on technology that is, at best, in the conceptual stages of development. More importantly, our view of advanced biorefineries is that we do not know today exactly what the technology behind these biorefineries will look like. Thus, the core R&D that we conduct today in support of advanced technology is less constrained by specific technical issues with a given thermal or biological processing scheme as envisioned for the emerging thermochemical and sugar platform technologies. This research is more fundamental in nature, asking broader questions about the processing of biomass that could well lead to new concepts for producing fuels and products.

The Program's integrated biorefinery projects are primarily divided into those projects that are based on the sugar platform and those that are based on thermochemical processing. This definition is somewhat arbitrary, as shown in the discussion above about biorefinery concepts that are mutually exclusive to one of these platforms. Nevertheless, we presume that the kind of ultimate integration of technologies (as shown in Figure 2) will occur further down the timeline. For each platform, we have projects that involve existing biorefineries and projects that involve emerging biorefinery concepts. There are, in fact, projects that combine both existing and emerging biorefinery schemes. By definition, none of the integrated biorefinery projects involve advanced biorefinery concepts.

In the category of existing biorefinery projects, there are two kinds of efforts. Projects that relate to improvements in existing technology applied in existing biorefineries and projects that involve introduction of emerging technology in existing biorefineries. The latter add relatively little value to the program in terms of our goal to deploy biomass technology that utilizes new biomass sources. The former provides a way to accelerate the testing of key technology components for emerging biorefineries in the context of existing commercial operations.

1.5 The Goals and Objectives of the Program

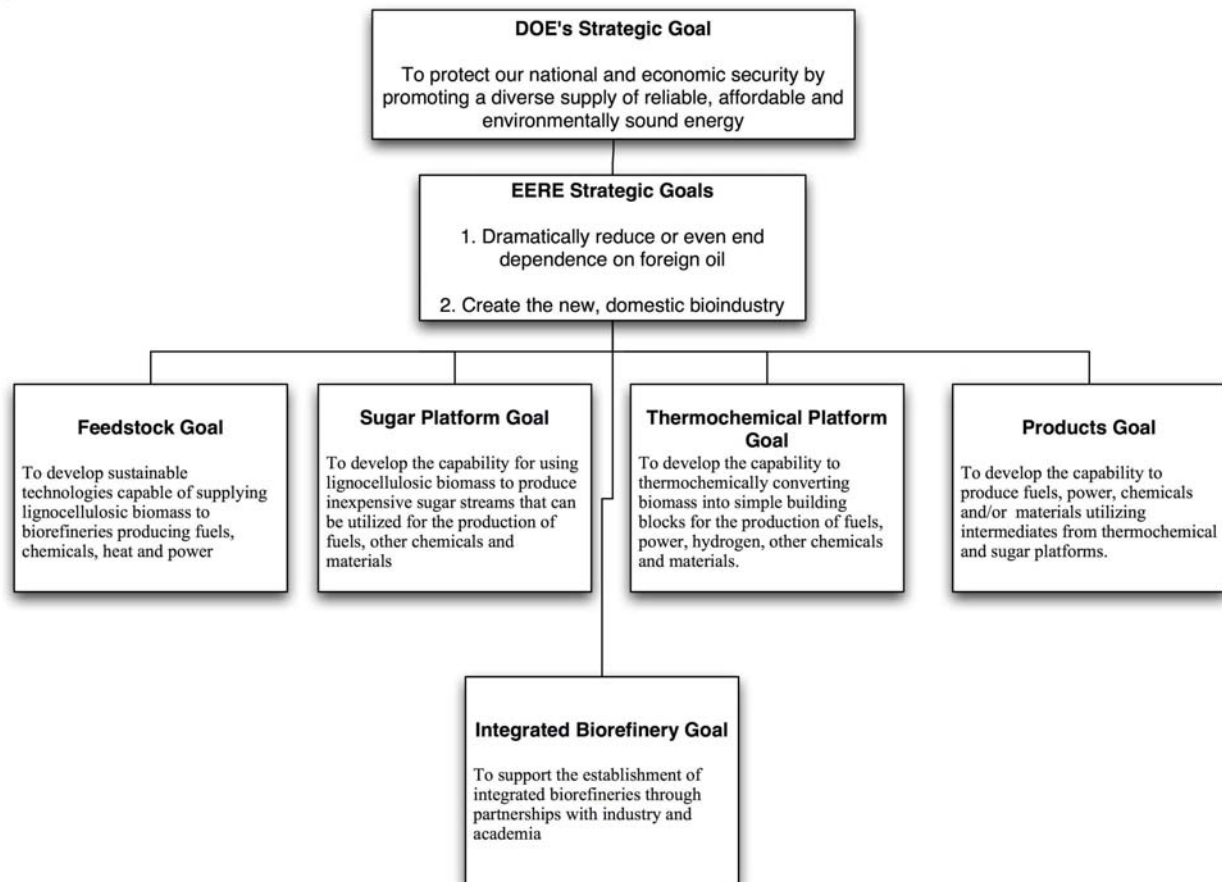


Figure 3: Alignment of Biomass Program Goals and Objective

2 Technical Plan

This section of the plan provides a detailed outline of the projects within the five R&D elements, or technology areas, of the Biomass Program:

2.1 Biomass Feedstock Interface R&D

2.2 Sugar Platform

2.3 Thermochemical Platform

2.4 Products (including fuels, chemicals, materials, heat and electricity)

2.5 Integrated Biorefineries

Figure 4 below shows the overall work breakdown structure for the Program. Program Management, covered in Section 3, includes program-wide activities such as planning, budgeting, execution, evaluation, technical integration, and analysis, as well as crosscutting activities such as outreach, education, and partnerships.

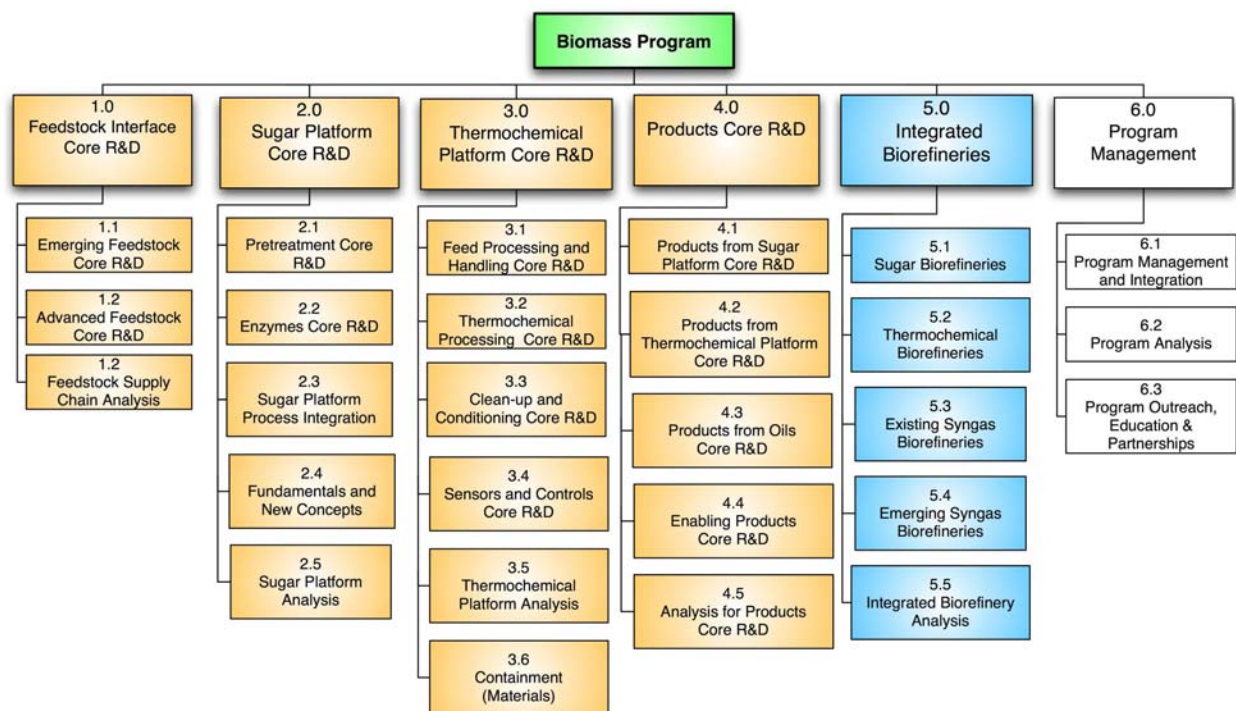


Figure 4: Overview of Biomass Program Work Breakdown Structure

2.1 Biomass Feedstock Interface R&D

The success of the biorefinery is critically dependent on having a large supply of low cost, high quality lignocellulosic biomass. The primary mission of the feedstock interface area is to work closely with the sugars and syngas conversion platforms to conduct the necessary R&D to meet their feedstock needs. Meeting the long-term needs of the biorefinery in a sustainable manner will require fundamental changes in our agricultural system and feedstock infrastructure system. Current technologies and agricultural practices are inadequate to meet this goal. New technologies and methods must be developed. The feedstock interface area will focus on developing the new technology and methods necessary in the

feedstocks infrastructure area to produce one billion tons of cellulosic feedstock per year in a sustainable manner at \$35/ton or less. This will require working closely with USDA,, growers, feedstock equipment manufacturers and processors to bring about the necessary changes in the agricultural system and to form integrated partnerships needed to support biorefinery development.

2.1.1 Technical Goals and Objectives

The overall goal of the biomass feedstocks interface R&D is to develop sustainable technologies capable of supplying lignocellulosic biomass to biorefineries producing fuels, chemicals, heat and power. The specific objectives of this research are:

- Develop sustainable biomass harvest and collection technologies capable of supporting an industry of up to 1 billion dry metric tons per year by 2050 goal and a near-term (2010) goal of supporting an industry of up to 150 million dry metric tons per year.
- Develop feedstock infrastructure technologies necessary to meet the \$35/ton price target while assuring an economically sustainable venture for growers, equipment manufacturers and biorefinery processors.
- Develop feedstock supply forecasts, models and analyses necessary to optimize feedstock supply chains to biorefineries and reduce supply risks.

The long term target of one billion tons of sustainable biomass supply is based on an estimate of the amount of biomass it would take to meet our current demand for gasoline, assuming that the biomass were converted to ethanol as a direct gasoline substitute. The more immediate goal of developing technology that could cost effectively deliver biomass at a level of up to 150 million dry metric tons per year is based on a recently developed roadmap for building a feedstock supply.¹ Note that this goal does not mean that there will be either a ready supply or a demand for 150 million tons per year of biomass. In fact, according to the plans presented here, the first full-scale commercial biorefineries will just be coming on line in this timeframe. The focus is on delivering technology that could address that level of demand.

2.1.2 Programmatic Status

Biomass feedstock availability is being fostered by the activities of two DOE national laboratories (ORNL and INEEL) who work in close collaboration with researchers at many USDA research laboratories and with private industry.

The INEEL in partnership with equipment manufacturers has made considerable progress and advancements in the feedstock infrastructure area over the past couple of years. Specifically as part of the ongoing highly successful OBP sponsored Selective Harvest and Multi-Component projects, considerable work and progress has occurred on what components of the agricultural residue biomass should be left in the field to address soil health and sustainability concerns and what parts should be harvested as biorefinery feedstocks. Also as part of these projects, numerical and computational models on mechanical fractionation and air stream biomass separation have been developed and integrated into a format that can be analyzed in virtual reality allowing virtual engineering models to be developed. These models are available to perform virtual engineering analysis of various biomass selective harvest techniques and methods that can be employed in a single-pass mode without negatively impacting the grain harvest. This innovative approach will significantly reduce the time and resources required to conventional engineering prototype approaches.

¹ *Roadmap for Agricultural Biomass Feedstock Supply in the United States*. Customer Review Draft, September 2003.

Equipment manufacturers are unwilling to make the significant resource investment required to develop the necessary biomass harvest and collection technology and equipment until significant markets exist for this technology and equipment. On the other hand, processors are unwilling to commit the resources required to build biorefineries until reasonable guarantees of feedstock supply, price and quality can be achieved. Initially processors thought that feedstocks needs could be largely met with existing harvest and collection technology and methods. However, more detailed analysis has shown this is not the case and new technology and methods are needed to achieve the feedstock needs of the biorefinery. Unfortunately, this puts the biorefinery concept in a precarious chicken or egg scenario that could significantly delay or threaten the eventual success of the biorefinery. This innovative virtual engineering prototyping approach is an innovative method for overcoming this dilemma.

The INEEL in partnership with growers and academia has also evaluated bulk processing, handling and transport technologies and methods as a more desirable, lower cost method than conventional baling for biorefinery feedstocks. Several concepts have been developed and conceptually evaluated that show considerable promise for meeting the feedstock availability and price targets. Additionally, the INEEL has evaluated several long-term storage technologies for both wet and dry storage options that are low cost with minimal degradation and losses.

Scientists at ORNL in collaboration with their research partners in private and public institutions have been engaged in developing and applying analysis tools in support of biomass feedstock development and supply systems for the last 15 years. Their research targets two highly integrated objectives: (A) providing robust forecasts and analyses of feedstock supply and supply, and (B) designing and implementing risk analysis tools for the development of supply logistics for biorefinery enterprises. The feedstock forecasts and analyses are designed to facilitate biorefinery development strategies, to support life cycle analyses of bioenergy and bioproducts, to support policy studies and policy development, and to respond to DOE's need to provide reliable estimates of energy feedstocks.

To provide forecasts and credible analyses of feedstock supply issues, ORNL has developed a set of integrated modeling tools (ORIBAS, POLYSYS, BIOCOST) and databases (ORRECL) for estimating current sustainable feedstock supplies and forecasting supplies from new resources such as energy crops. These modeling tools encompass economic, geographic and environmental constraints in assessing the availability of biomass wastes, agricultural residues and potential energy crops. Biomass resource estimates are sensitive to environmental and soil conservation issues, to the scale of the processing facility, and to the economics of farming as an enterprise. The models can be applied to provide estimates of the impacts of different development and policy scenarios on the cost and availability of biorefinery feedstocks. Recently ORNL, in concert with NREL and Kansas State University, developed a soils and crop management based approach for estimating sustainable removal of crop residues and used that approach to estimate current and forecast potential ag residue supplies from all important corn and wheat soils in the US...

ORNL research also focuses on the development and application of a logistics model of supplying feedstock from an agricultural setting to specific biorefineries. The model takes into account constraints on the supply chain from local climatic conditions, farm size and yields, transportation and storage network, supply and demand schedules, and feedstock quality specifications. The model output consists of costs and energy and utilization rate of current or future available agricultural residue collection systems. The model will be linked to other ORNL tools such as the ORIBAS transportation model and eventually to NREL's biorefinery models to create an integrated model that can be used to assess the value and benefits of the proposed equipment and feedstock storage concepts being developed by DOE, USDA and NBC researchers. ORNL and INEEL scientists will work closely together to generate the experimental and operational data needed to validate and use the model. The supply chain model will be designed to directly interface with process models being developed by NREL and others.

2.1.3 Technical Barriers

The lack of a sustainable supply of biomass is, ultimately, the barrier that must be addressed by the program vis-à-vis feedstocks. This is not to say that a biomass supply does not exist. It means that we cannot state with certainty the amount, cost and impacts of using current or new supplies of biomass. Figure 5 shows the hierarchy of barriers from the most general (a sustainable supply) to the specific barriers facing both emerging and advanced biomass technology. Barriers to sustainability include the high cost of biomass, as well as the lack of understanding of the environmental, economic and social impacts of creating a large biomass supply.

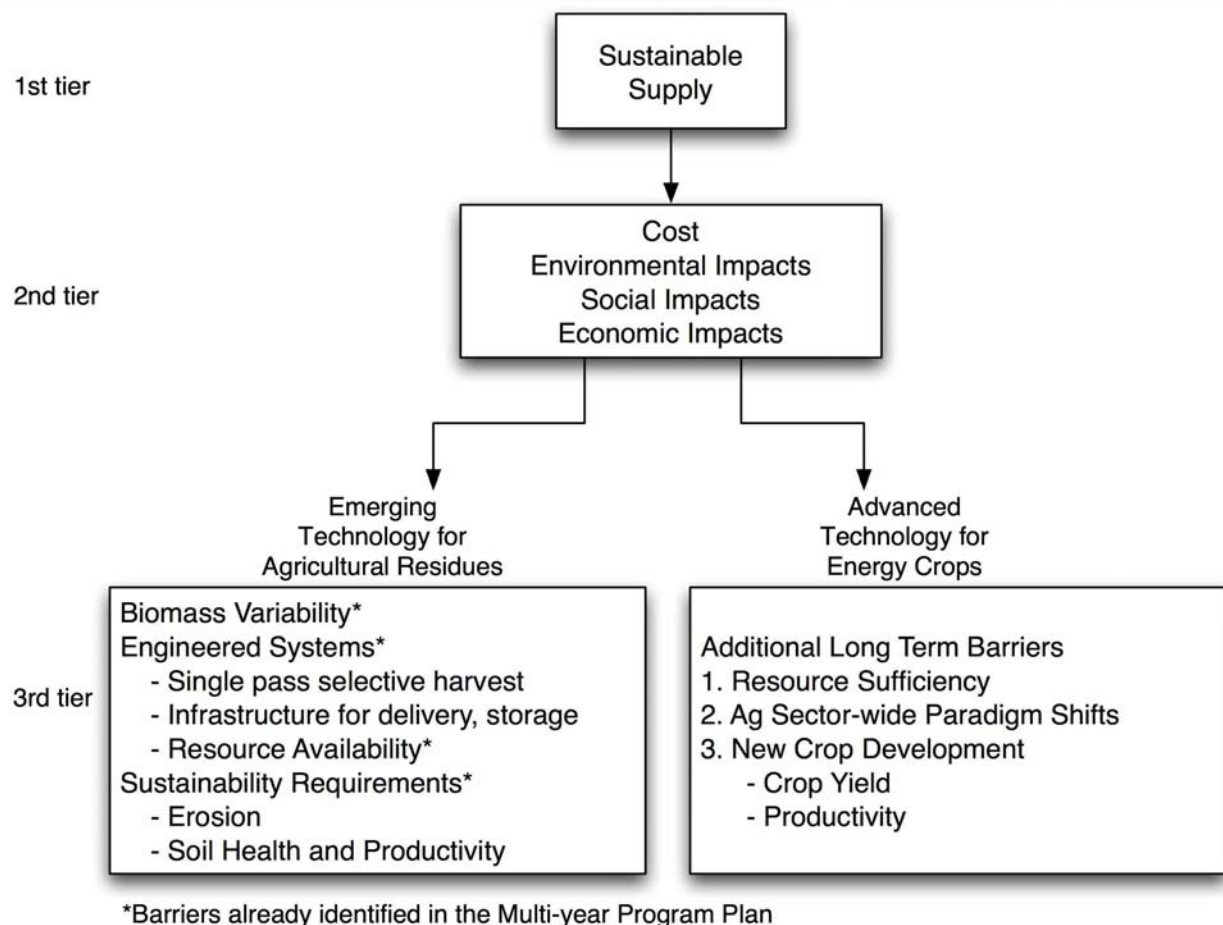


Figure 5: The Hierarchy of Technical Barriers Facing the Feedstock Interface Area

In FY 2003, the Biomass Program conducted a series of meetings across the country involving companies pursuing biorefineries, equipment manufacturers, environmental groups, transporters, farmers and USDA. The groups represented the collective expertise necessary to address the needs of an emerging biomass industry based on agricultural residues. The groups identified the performance targets, the technical barriers and the top priority research needed by OBP and USDA to achieve the near-term goals. These groups identified the following feedstock-related barriers for the emerging industry:

- *Biomass Variability*

The characteristics of biomass can vary widely in terms of physical and chemical composition, size, shape, moisture content, and bulk densities. These variations can make it difficult (or costly) to supply biorefineries with feedstocks of consistent quality year-round.

- *Engineering Systems*

Development of a reliable and cost-competitive feedstock infrastructure requires the combining together of several engineering systems to create total feedstock supply chains. Current systems cannot meet the capacity, efficiency or delivered price requirements of large biorefineries, nor can they effectively deal with the variability that is inherent in biomass feedstock supplies. Collection today requires removal of residue in a second pass through the field after harvest of the grain. Furthermore, current biomass harvest and collection methods do not have the ability to selectively and with minimal impact harvest the desired components of the biomass to meet sustainability drivers.

- *Resource Availability*

The lack of credible data on price, location, quantity, and quality of biomass creates uncertainty both for investors and for developers of emerging biorefinery technologies

- *Sustainability Requirements*

The lack of information and decision support tools to predict effects of residue removal as a function of soil type, and the lack of a selective harvest technology that can evenly remove only desired portions of the residue make it difficult to assure that residue biomass will be collected sustainably. USDA researchers and regulators will need to play a major role in understanding sustainable limits to collection of biomass.

In the long term, large scale replacement of petroleum calls for the introduction of a new generation of energy crops that can dramatically increase the potential supply of energy from biomass, while not sacrificing the important role that agriculture plays in meeting our society's need for food and fiber. The barriers facing this long term industry include the same ones facing the emerging industry plus a number of new issues such as:

- *Resource Sufficiency*

There is no future vision for biomass in U.S. agriculture. We cannot understand what kind of role biomass can play in America's energy future until a comprehensive vision for how and at what level biomass can impact energy supply. Lacking that vision, biomass will not be a priority in renewable energy.

- *Ag-Sector-wide Paradigm Shift*

Energy crops, per se, cannot simply be added to the list of crops and products that are handled by U.S. farmers. Energy production from biomass calls for a complete rethinking of farming in America, and it may involve dramatic changes in agriculture that may take some time bring about.

- *New Crop Development*

Large and cost-effective energy production on a scale that significantly impacts petroleum use calls for new crops with yield and productivity not currently available.

The main focus on Feedstock Interface area is not on the long term barriers. This effort is more appropriately addressed directly by USDA.

Figure 6 shows the cost impacts of addressing the barriers of single-pass harvesting and selective harvesting.

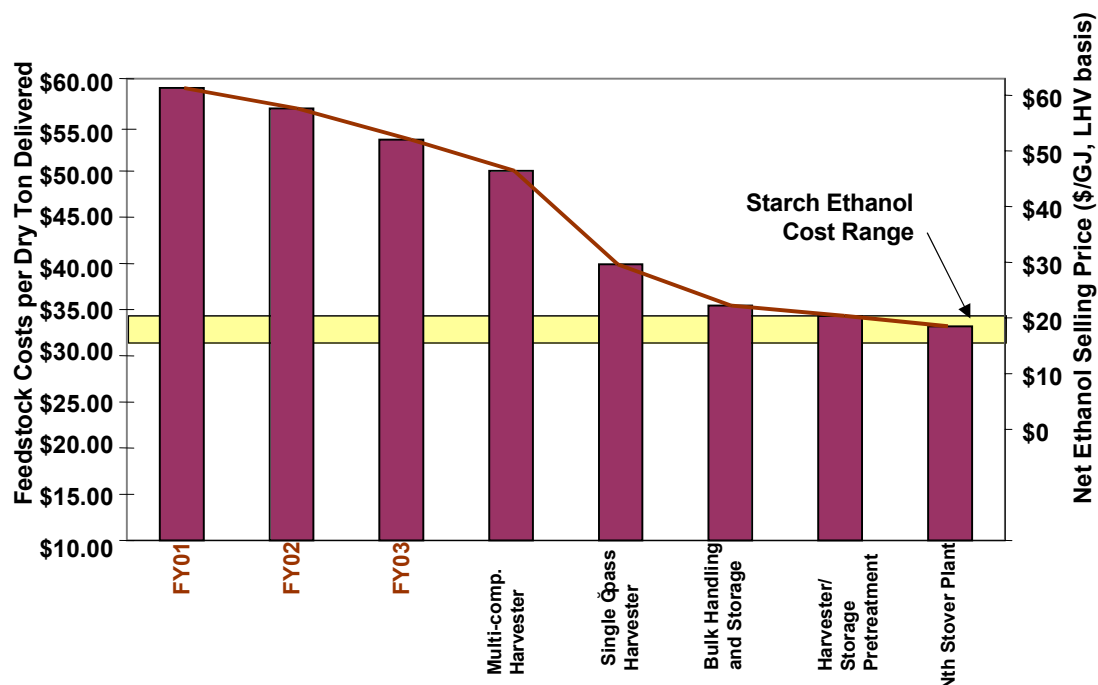


Figure 6: Translating Reductions in Technical Barriers to Feedstock and Ethanol Cost (Foust 2003)

2.1.4 Technical Approach

The work breakdown structure for the feedstock interface area is shown in Figure 7. The research is divided into three subareas:

- Emerging Feedstock Barrier R&D (WBS # 1.1)
- Advanced Feedstock Barrier R&D (WBS # 1.2)
- Feedstock Supply Chain Analysis (WBS # 1.3)

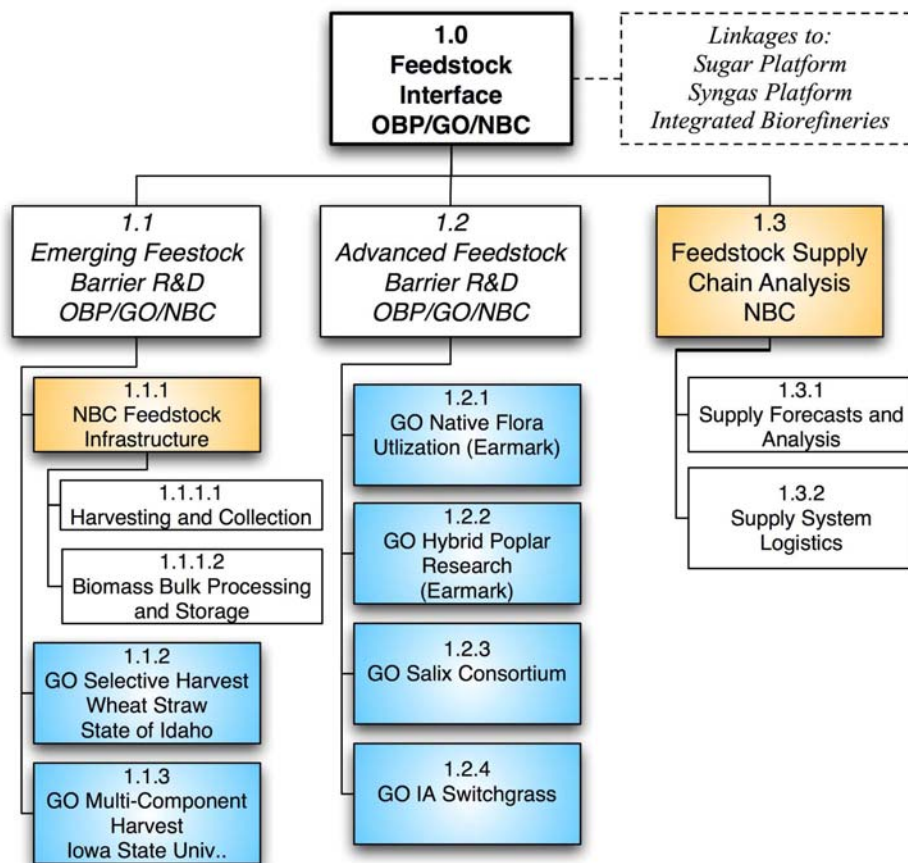
Figure 8 highlights the key activities and their milestones for the feedstock interface core R&D. Detailed project descriptions are provided in the Appendix.

The focus of the Emerging Feedstock Barrier R&D is on solving the engineering systems barriers of collection, delivery and storage of agricultural residues. It represents the bulk of the technical work in this area. Two feedstock infrastructure projects are being led by Idaho National Energy and Environmental Laboratory: one on the development of a harvester capable of handling multiple components of the crop and selectively harvesting those portions of the plant optimally suited for various downstream processors, while returning components that best meet the needs of good soil management. The second project looks at the storage and delivery elements of the feedstock infrastructure. The three remaining projects under this subarea are independent projects looking at similar feedstock infrastructure technologies. It will be important to ensure regular communication and coordination among all of these projects in order to improve the likelihood of success of developing the technologies that will be needed to deliver agricultural residues within the cost constraints of the emerging biorefineries.

Partnerships with growers, equipment manufacturers, transporters and processors will be critical to successful commercialization of the elements of this new feedstock infrastructure. At the same time, the feedstock area will work closely with the biorefinery technologies to ensure infrastructure compatibility. The feedstock interface area will work proactively with USDA, growers and grower organizations and

environmental groups to form the vertical partnerships and collaborative efforts needed to support biorefinery development.

The Feestock Supply Chain Analysis area will focus on the development of analytical tools for the optimization overall logistics of the infrastructure system, as well as tools for estimating the amount and price of agricultural residues and future energy crops.



NOTE:

Projects with "NBC" at the beginning are managed by the National Bioenergy Center
 Projects with "GO" at the beginning are managed by the USDOE Golden Field Office
 Projects with "NETL" at the beginning are managed by the National Energy Technology Center
 Shaded boxes are "projects" reported on quarterly (Orange for NBC-managed projects and blue for field managed projects)

Figure 7: Work Breakdown Structure for Feedstock Interface Core Barrier R&D

The program has, over the past few years, reduced its efforts in the area of Advanced Feedstock Barrier R&D. The bulk of this work will become the responsibility of USDA. The six projects that remain in this area are a combination of Congressional earmarks and “legacy” projects first developed under previous programs that have now been combined in the Biomass Program.

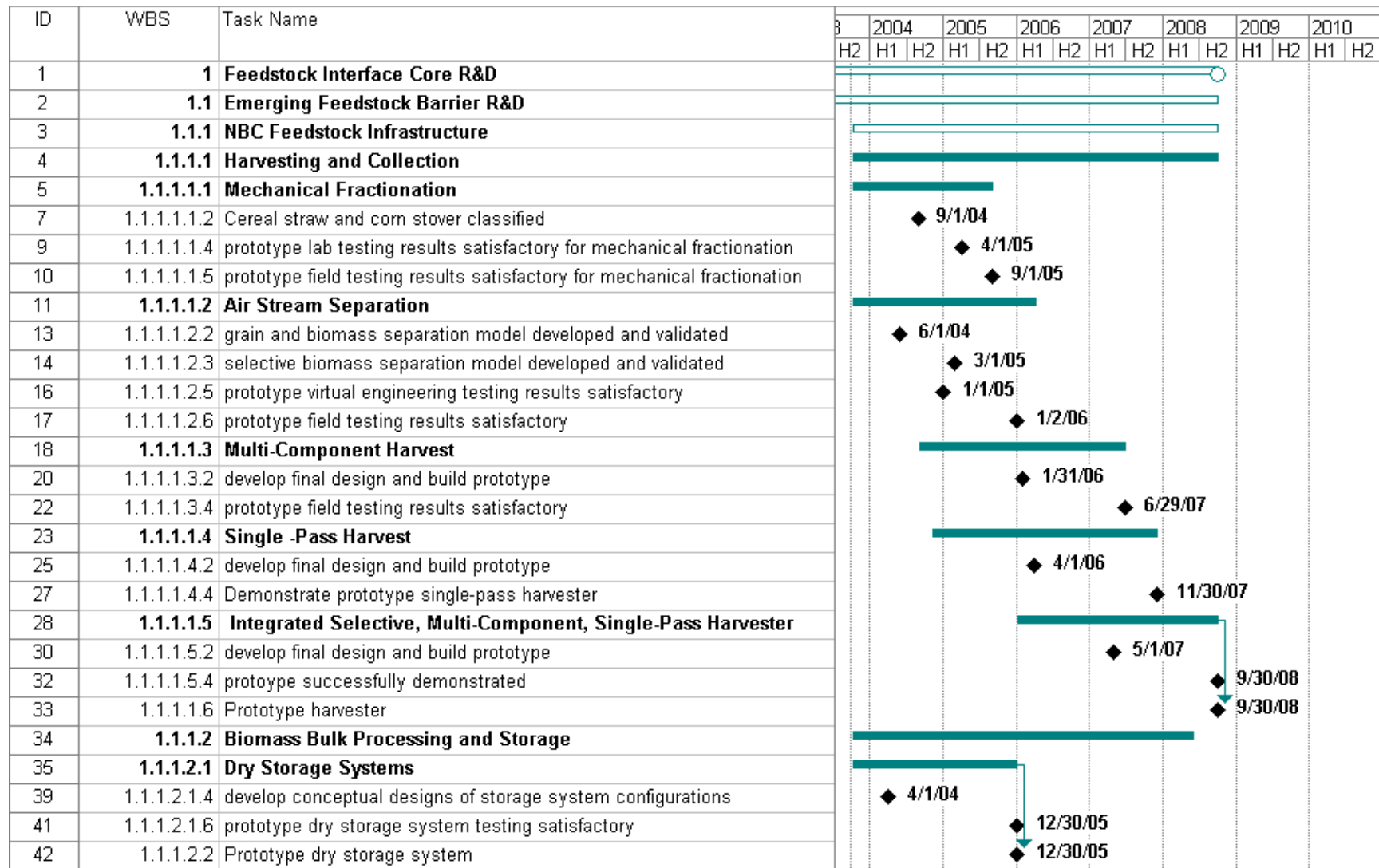


Figure 8: Key Activities and Milestones for WBS Area #1 Feedstock Interface Core R&D

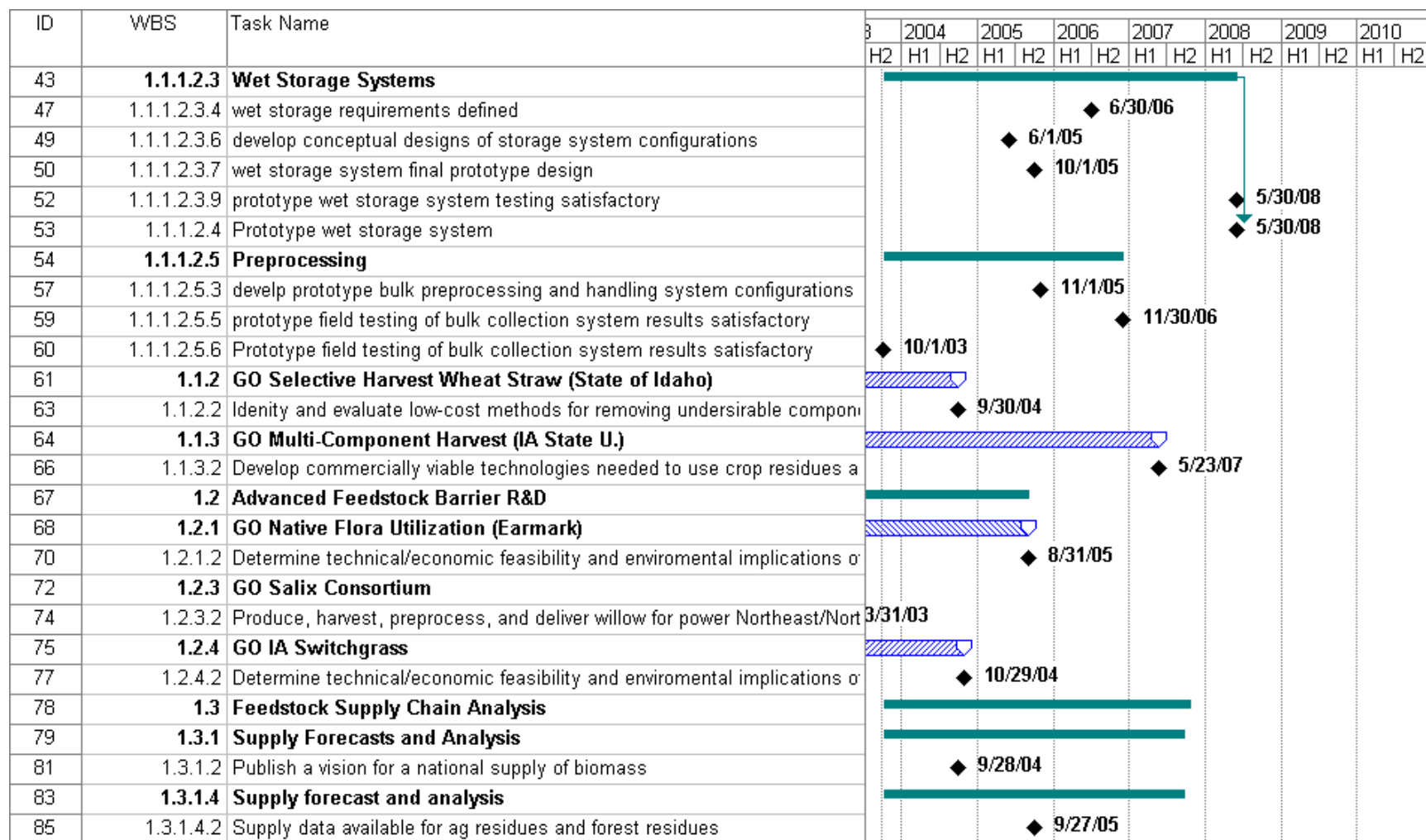


Figure 8: Key Activities and Milestones for WBS Area #1 Feedstock Interface Core R&D (cont'd)

Table 1: Feedstock Interface Projects and Milestones

Biomass Program Goal: To develop sustainable technologies capable of supplying lignocellulosic biomass to biorefineries producing fuels, chemicals, heat and power.

Objective:

- Develop selective biomass harvest and collection technologies necessary to meet the 1 billion tons per year by 2030 goal and a near-term (2010) goal of 300 million dry tons per year in a sustainable manner.
- Develop feedstock infrastructure technologies necessary to meet the \$35/ton price target while assuring an economically sustainable venture for growers, equipment manufacturers and biorefinery processors.
- Develop feedstock supply forecasts, models and analyses necessary to optimize feedstock supply chains to biorefineries and reduce supply risks.

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
Engineering Feedstock Barrier R&D OBP/GO/NBC	1.1.1.1 Harvesting and Collection	<ul style="list-style-type: none">• Biomass cannot be selectively harvested to meet sustainability and availability targets.• Grain harvest occurs in a short time window and modern day combines are operating at their maximum capacity.• Current biomass harvest technologies require multiple passes across the field increasing costs and soil compaction.	09/2008: Successfully demonstrate multi-component selective harvest system capable of operating in a single-pass to produce high quality, low cost biomass feedstocks in a sustainable manner.
	1.1.1.2 Biomass Bulk Processing and Storage	<ul style="list-style-type: none">• Handling and transportation challenges due to low bulk-density of biomass.• Inability to monitor fluctuations in feedstock properties.• Cost-effective collection and transport difficult due to low residue tons/acre.• Storage costs and risks due to short crop residue harvest window	12/2005: Successfully demonstrate prototype dry storage system. 11/2006: Prototype field testing of bulk collection systems satisfactory 05/2008: Prototype wet storage system testing satisfactory

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	1.1.2: GO Selective Harvest Wheat Straw (State of Idaho)	<ul style="list-style-type: none"> Biomass cannot be selectively harvested to meet sustainability and availability targets Feedstocks – engineering systems Sugar biorefinery – pretreatment Products – Syngas Conversion 	<p>10/2003: Test physical separation and biological pretreatment of wheat straw for use in combustion and thermo-plastic applications</p> <p>9/2004 Create a preliminary full-scale design for modified/new equipment to harvest, handle, and store straw stems.</p> <p>9/2004 Complete feedstock testing for combustion and straw-thermoplastic composites.</p>
	1.1.3: GO Multi-Component Harvest (Iowa State University)	<ul style="list-style-type: none"> Consistency and quality of raw materials; Biomass cannot be selectively harvested to meet sustainability and availability targets. 	<p>10/2004: Evaluate genetically altered low lignin wheat straw.</p> <p>05/2007: Test pre-commercial intelligent control systems for selective harvest of wheat straw.</p>
Advanced Feedstock Barrier R&D OBP/GO/NBC	1.2.1 GO Native Flora Utilization (Earmark)	<ul style="list-style-type: none"> Broad ranging from feedstock production to use. 	08/2005: Perform research on the technical and economical feasibility and environmental implications of developing a cellulosic ethanol industry moving west from Minnesota into North and South Dakota
	1.2.2 GO Hybrid Poplar Research (Earmark)	<ul style="list-style-type: none"> Broad ranging issue for implementing fast growing tree plantations. 	N/A

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	1.2.3 GO Salix Consortium	<ul style="list-style-type: none"> Inefficient willow harvesting Lack of delivery systems for willow biomass 	10/2003 Process improvements B Double harvester and chipper performance 10/2003 Secure commercial hauling contractors and delivery agreements 10/2003 Establish permanent harvesting operations 10/2003 Finalize logistics and accounting for WilloWatts at Dunkirk
	1.2.4 GO IA Switchgrass	<ul style="list-style-type: none"> Feedstocks engineering systems 	1/2004 Complete Interim Test Burn at Ottumwa Generating Station 5/2004 Finalize Permanent Installation Equipment Design 5/2005 Complete Long-Term Test Burn at Ottumwa Generating Station 9/2005 Complete all market development issues, including contractual arrangements, required to support the commercial use of biomass to generate energy.
Feedstock Supply Chain Analysis	1.3. Feedstock Supply Chain Analysis	<ul style="list-style-type: none"> Lack of credible data on price, location, quantity, and quality of biomass 	09/2004: Complete national biomass vision (with USDA, others) 09/2005: Complete supply-cost database for existing biomass feedstocks (national forest residues) 09/2006: Complete supply-cost database for energy crops 09/2007: Publish advanced technology forecast for agricultural residues

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	1.3.1 Supply Forecasts and Analysis	<ul style="list-style-type: none"> Lack of credible data on price, location, quantity, and quality of biomass. 	<p>9/2004 Document FY2003 analysis of current sustainable corn stover and wheat straw supplies.</p> <p>9/2004 Stage gate review of existing supply data & forecasts (ag residues, energy crops, forest residues, urban wood wastes, and primary mill wastes).</p> <p>9/2004 Develop and document a vision for achieving an annual biomass supply of 1 billion dry tons under \$35/ton, identifying the feedstock handling and agricultural production changes that will be needed to support a biorefinery industry.</p> <p>9/2004 Assisting NREL in a lifecycle assessment of biohydrogen with a completion date sometime in 2005.</p> <p>9/2005 Develop regional feedstock transportation cost estimates, factoring in differences in feedstock supply density and feedstock types and research findings from the feedstock infrastructure task.</p>

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	1.3.2 Supply System Logistics	<ul style="list-style-type: none"> • Feedstock supply is a significant cost component of bio-based fuels, products or power. • The uncertainty and fear of feedstock supply chain risks is a major barrier to procuring capital funding for start-up biorefineries. 	<p>FY03 Develop a flow network to represent biomass collection and delivery processes</p> <p>Develop mathematical models describing processes and constraints; compile operational data (soil and climate), and integrate the model with other system tools such as GIS.</p> <p>Validate the model using specific field data (mostly from harvest and storage research efforts at INEL) and expert advice.</p> <p>Collaborate directly with the existing industry and planned biorefineries to implement the model using specific soils, climate and weather information associated with locations under consideration for biorefinery development.</p>

2.1.5 Resource Allocation Plan

The resource requirements for the projects in the feedstock area are shown in Table 2 and in Figure 9.

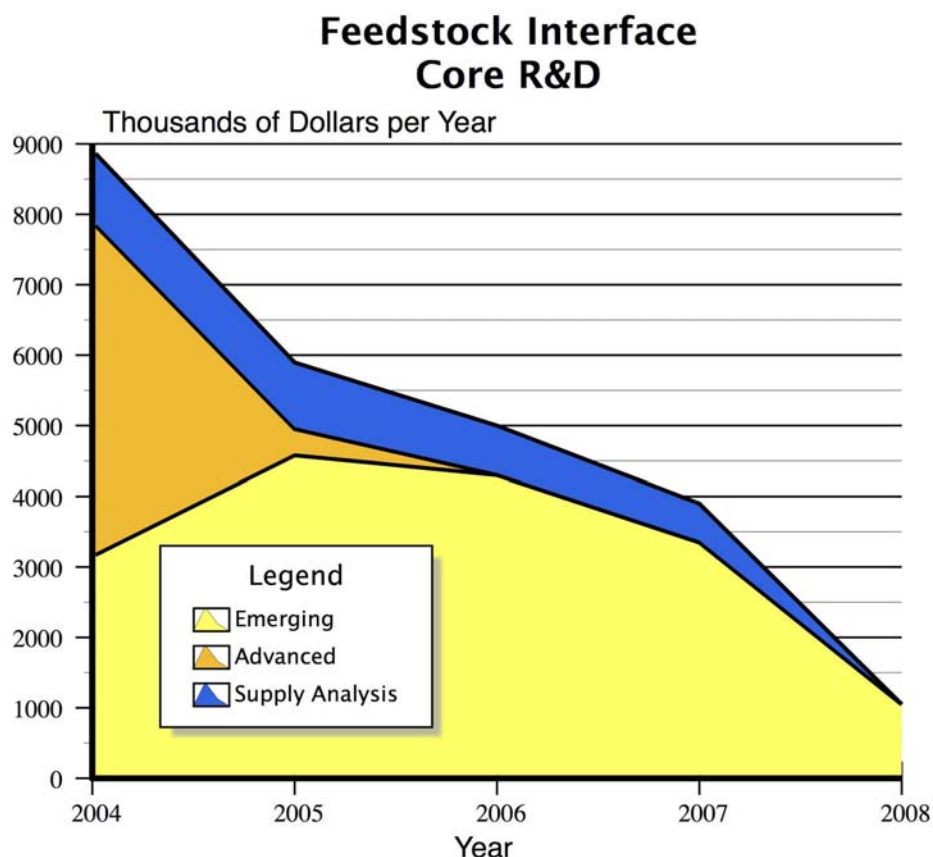


Figure 9: Feedstock Interface Core R&D Resource Plan

The high level of spending in 2004 reflects the last year of spending on the Iowa Switchgrass project in Chariton Valley. The lion's share of the research spending for feedstock is related to meeting the needs of agricultural residue collection and delivery infrastructure in time for the first corn stover based biorefineries anticipated to be in place by 2010. In addition, we are providing support for resource analysis related to understanding the cost, amount and sustainability of biomass supplies. Planned spending drops off by 2008 assuming that new feedstock harvest and collection technology will shift to the private sector as demand for biomass supplies are realized.

Table 2: Feedstock Interface Resources

WBS	Title	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
1	Feedstock Interface Core R&D	\$7,039	\$7,729	\$7,729	\$7,411	\$8,865	\$5,896	\$4,999	\$3,899	\$1,050
1.1	<i>Emerging Feedstock Barrier R&D Subtotal</i>	\$0	\$690	\$690	\$0	\$3,172	\$4,579	\$4,299	\$3,349	\$1,050
1.1.1	NBC Feedstock Infrastructure Subtotal	\$-	\$-	\$-	\$-	\$2,373	\$3,780	\$3,500	\$2,550	\$1,050
1.1.1.1	Harvesting and Collection					\$1,232	\$1,900	\$1,750	\$1,400	\$600
1.1.1.2	Biomass Bulk Processing and Storage					\$1,141	\$1,880	\$1,750	\$1,150	\$450
1.1.2	Go Selective Harvest Wheat Straw (State of Idaho)		\$690	\$690						
1.1.3	Go Multi-Component Harvest (Iowa State University)					\$799	\$799	\$799	\$799	
1.2	<i>Advanced Feedstock Barrier R&D Subtotal</i>	\$7,039	\$7,039	\$7,039	\$7,411	\$4,673	\$372	\$-	\$-	\$-
1.2.1	GO Native Flora Utilization (Earmark)				\$372	\$372	\$372			
1.2.2	GO Hybrid Poplar Research (Earmark)									
1.2.3	GO Salix Consortium	\$2,738	\$2,738	\$2,738	\$2,738					
1.2.4	GO IA Switchgrass	\$4,301	\$4,301	\$4,301	\$4,301	\$4,301				
1.3	<i>Feedstock Supply Chain Analysis</i>					\$1,020	\$945	\$700	\$550	

2.2 The Sugar Platform

Lignocellulosic biomass is essentially a heterogeneous composite of interlinked hemicellulose, cellulose, and lignin polymers. Cellulose, a crystalline polymer of glucose, and hemicellulose, a non-crystalline polymer of the hexoses D-glucose, D-galactose and D-mannose and the pentoses D-xylose and L-arabinose (and minor levels of acetic and uronic acids), together make up the carbohydrate portion of biomass, comprising approximately 2/3 of biomass on a dry weight basis. Lignin, a high-energy polymer of alkyl-linked phenolic units, comprises the majority of the remainder. Other minor components include protein, oils, and waxes.

Lignocellulosic biomass can be converted into mixed sugars solutions plus lignin-rich solid residues by the sequential use of thermochemical pretreatment and enzymatic saccharification. Technical barriers impacting cost and performance currently hinder commercialization of this technology; projected operating and capital equipment costs for facilities implementing the best developed technology exceed those of current grain-based alternatives. The Office of the Biomass Program (OBP) and its predecessors have historically supported fundamental and applied research and technology development targeted at producing low cost sugars from lignocellulosic biomass with fuel ethanol as an end product. Figure 10 shows a simple process flow diagram of how the Program's view of this technology has evolved into the concept of the emerging sugar biorefinery—a concept that is central to most of the work planned in this core R&D area.

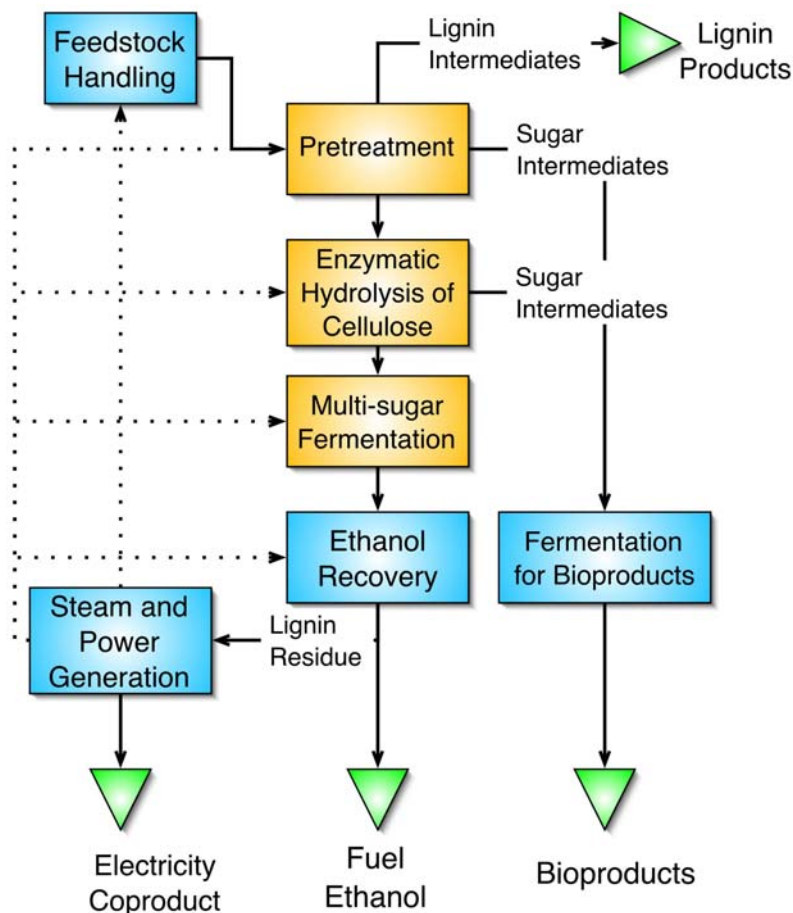


Figure 10: The Emerging Sugar Biorefinery

2.2.1 Technical Goals and Objectives

The technical goal of the Sugar Platform is to develop the capability for using lignocellulosic biomass to produce inexpensive sugar streams that can be utilized for the production of fuels, other chemicals and materials. The 2010 goal is to reduce the cost of a mixed, dilute sugar stream suitable for fermentation to ethanol, in a mature biochemical plant, from the 2003 estimated cost of \$0.14 per lb to \$0.07 per lb.

2.2.2 Programmatic Status

The Sugar Platform is derived from work supported by the previous Office of Fuel Development targeting production of fuel ethanol from lignocellulosic biomass. With the reorganization of the Office of Energy Efficiency and Renewable Energy, the efforts to produce inexpensive, mixed sugar streams have been separated from the production of fuel ethanol which now lies in the Products area. The model process for lignocellulosic saccharification, selected to provide necessary focus for a resource limited effort, includes thermochemical pretreatment followed by enzymatic saccharification. Modest efforts with alternative model processes have been and continue to be included in the our research. Status of the work on the Sugar Platform core R&D is summarized below:

Analysis in Support of the Sugar Platform

- A Technoeconomic model of Dilute acid pretreatment/cellulase saccharification/ethanol process has been developed and refined

Pretreatment

- Preliminary Technoeconomic analysis has been extended to alternative pretreatment chemistries represented in the CAFI consortium.
- Improved cellulose digestibility has been demonstrated with pretreated and hot washed material utilizing a Pneumapress.
- Improved total saccharification with dilute acid has been demonstrated with a novel “Shrinking Bed” reactor design.

Enzyme Hydrolysis

- Subcontracts with major enzyme producing companies have provided 10X cost reductions for cellulases.
- Different performance in alternate cellulase assays has suggested a need to identification of factors to clarify results and an opportunity for cellulase improvement
- Thermotolerant and high specific activity glycosyl hydrolases have been identified.
- Sugar Platform Integration
- Pretreatment has been demonstrated at solids levels approaching 35%.
- Rapid analysis methods have been developed for corn stover and pretreated corn stover utilizing multivariant analysis to correlate near-infrared spectroscopy with wet chemical analyses.
- Advanced Fractionation and Concepts –
- Molecular Mechanics Modeling has indicated the presence of high density water above the hydrophobic face of cellulose.
- The crystal structure of a highly active thermophilic family 12 endoglucanase has been solved.
- A profile of thermal-up mutations in a family 1 beta-glucosidase has been developed.

2.2.3 Technical Barriers

The barriers for the Sugar Platform can be viewed as a hierarchy of barriers with each level more specifically targeted to a more specifically defined technology as shown in Figure 11. At the most general tier, the barrier to commercial success is conversion cost for biomass to sugar(s). At a second level, cost elements are described at a generic level; product yield, product concentration, conversion rate, product quality, and capital investment. A selection of a specific technology allows greater specificity of barriers in terms of process unit operations that must perform to standards, and process integration that must be achieved to reach cost targets.

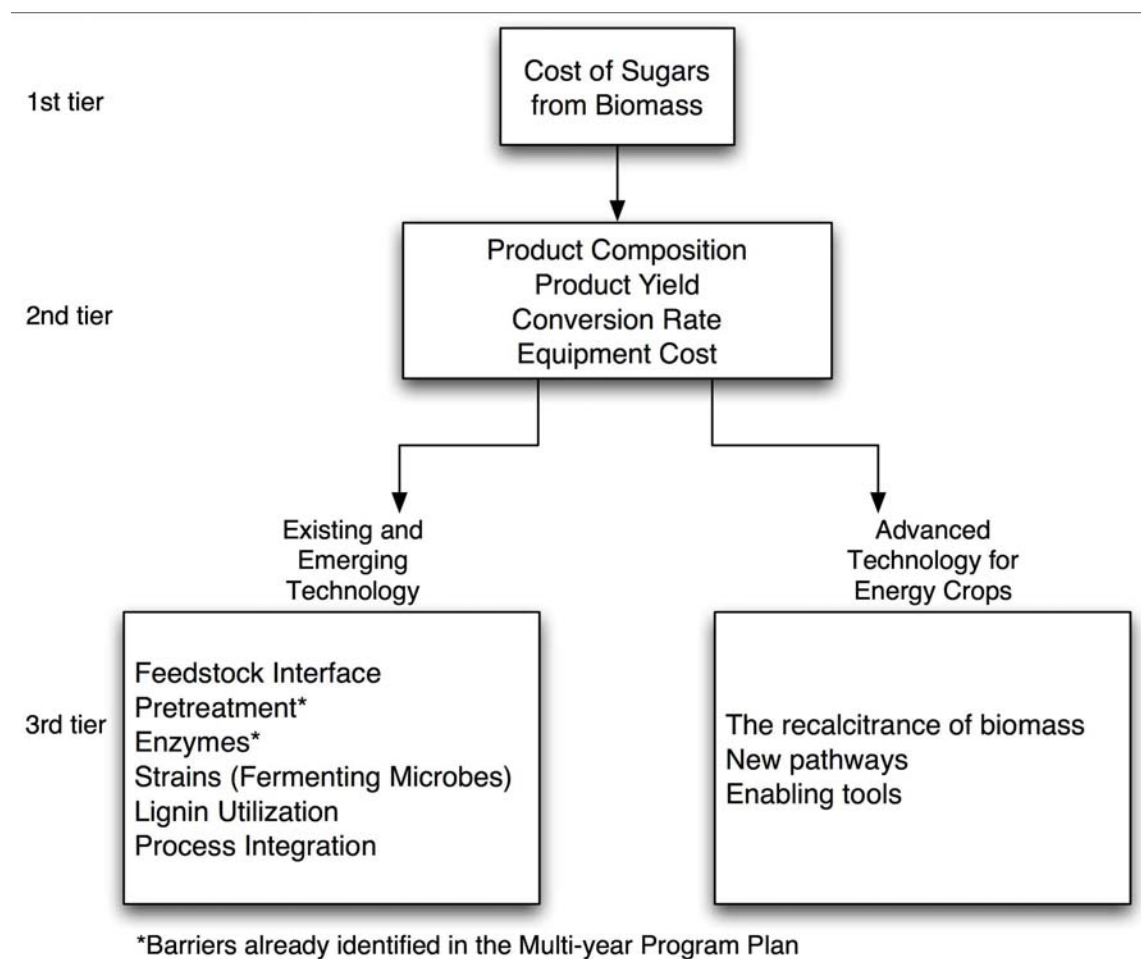


Figure 11: A Hierarchy of Barriers to Deployment of the Sugar Platform

In DOE's current multi-year program plan (MYPP), the barriers identified for the sugar platform are based on implicit assumptions about the nature of the technology being used. The MYPP identifies only two technical barriers: enzymatic hydrolysis and pretreatment. As shown in the hierarchy of barriers above, these two barriers are specific to the enzymatic hydrolysis process that now serves as the basis for improvements to existing sugar-based biorefineries (dry and wet mill corn processors, for example) and emerging biorefinery concepts that include lignocellulosic biomass, which are being developed by a number of DOE industry partners. Within the context of the existing and emerging biorefinery work, we have added a number of barriers. The critical list of barriers to deployment of existing and emerging sugar-based biorefineries now include:

- *The problem of **feedstock variability** and its effect on process performance.*

Much of the focus of OBP-supported work over the past several years has been on corn stover as an available low cost feedstock. Our experience with corn stover has proved that it is sufficiently variable in carbohydrate content to warrant the development of analytical methods that provide real time information on potential sugar yield.

- *The need for a **cost effective pretreatment** step to release hemicellulose sugars and improve the ability to hydrolyze cellulose.*

Thermochemical prehydrolysis of biomass, typically referred to as pretreatment, is required to open up the structure of biomass and increase its susceptibility to subsequent enzymatic hydrolysis by cellulase enzymes. In the nearer term, developing lower cost pretreatments depends upon the ability to process the biomass at high solids levels in reactors fabricated out of cost-effective materials of construction. Pretreatment catalyst usage and the requirement for any catalyst recovery and recycle also must be considered in the overall costs of the pretreatment step. In the longer term, continued significant cost reductions in pretreatment technologies require developing a better understanding of pretreatment process chemistries and elucidating the roles that biomass structure and composition play in biomass recalcitrance.

- *The lack of **cost effective enzymes** to catalyze the hydrolysis of cellulose to glucose.*

Cellulase enzymes remain a significant portion of the projected production cost of sugars from lignocellulosic biomass, despite approximately tenfold cost reductions achieved in recent OBP-sponsored cost reduction subcontracts to industry. In the nearer term, reducing the cost of enzymatic hydrolysis depends upon developing lower cost enzyme production technologies (\$/kg enzyme) in conjunction with identifying more efficient enzyme preparations and enzyme hydrolysis regimes that permit lower dosages (kg enzyme/kg substrate) to be used. Substrates that allow for enhanced enzymatic hydrolysis as a result of improved pretreatment processes can also impact the enzyme usage requirements and thus the overall costs of enzymes for production of sugars. In the longer term, enzymes that exhibit high thermostability and substantial resistance to sugar end-product inhibition will be essential to fully realize enzyme-based sugar platform technology. The ability to develop such enzymes and consequently very low enzymatic hydrolysis technology requires increasing our understanding of the fundamental mechanisms underlying the biochemistry of enzymatic cellulose hydrolysis, including the impact of biomass structure on enzymatic cellulose decrystallization.

- *The need for **robust biological and chemical catalysts** capable of utilizing all sugars in biomass and able to handle pretreated biomass.*

Sugar solutions resulting from thermochemical pretreatment are impure, containing a mixture of sugars as well as a variety of non-sugar components. Potential impurities include acetic acid liberated upon hydrolysis of hemicellulose, lignin-derived phenolics solubilized during pretreatment, inorganic acids or alkalis or other compounds introduced during pretreatment, various salts, and hexose and pentose sugar degradation or transglycosylation products. Mixed sugars alone provide significant conversion challenges for many target products, and the presence of other compounds that can be inhibitory to microbial fermentation or biocatalysis or which can poison chemical catalysts, further adds to these technical challenges. Despite significant progress in developing microorganisms capable of producing ethanol from all biomass sugars at high selectivity and yield, strains that perform robustly on pentoses remain elusive; much greater hardness is typically observed in hexose-utilizing strains. Even less progress has been made in developing chemical catalysts for high selectivity mixed sugar conversion. Currently, neither appropriate microorganisms nor appropriate chemical catalysts are available that enable economic utilization of complex, impure, biomass-derived sugar streams. Thus, in the nearer term, more economical methods of separating sugars prior to conversion, or of separating products from sugar mixtures after conversion, are needed to exploit existing microbial, enzymatic, and chemical catalysts. In the longer term, efforts must continue to develop harder and more effective microbial and chemical catalysts.

- *The uncertainty surrounding **the use of lignin** for producing heat, power and other products.*

The process residues remaining after the conversion of the carbohydrates in biomass to sugars contain mostly lignin, a relatively high heat content material that we assumed is used in the sugar biorefinery as its sole source of heat and power. There is, however, no experience working with this relatively high moisture content material in commercial boiler/turbogenerator systems. The potential for generating higher value products from lignin is an unpopulated target of the Products area.

- *The lack of experience with and understanding of the complex interactions among each of the steps in **an integrated process**.*

Beyond the core saccharification steps of pretreatment and enzymatic hydrolysis, process integration remains a key technical barrier hindering development and deployment of biomass sugar platform technology. Sugar platform technology currently presents large scale up risks because there is a dearth of high quality performance data on integrated processes carried out at the high solids conditions required for industrial operations. Nearer term process integration work is essential to characterize the complex interactions that exist between many of the processing steps, to identify unrecognized separation requirements, process bottlenecks, and knowledge gaps, as well as to generate the integrated performance data necessary to develop predictive mathematical models that can be used to guide process optimization and scale up. Demonstrating integrated process technology is also a prerequisite to producing process intermediates (e.g., pretreated solids that are required to evaluate the progress of enzyme cost reduction efforts) and residues (e.g., residual lignaceous process solids that are needed to validate their assumed value as an energy source for producing steam, heat, and electricity, or as a substrate for gasification to produce a biomass-derived synthesis gas or pyrolysis to produce a biomass-derived high-energy liquid).

By expanding the view of the technology barriers beyond the existing and emerging technology to consider future technology options yet to be determined, we have identified a number of more fundamental barriers, such as:

- *The lack of understanding of the root causes of **the recalcitrance of biomass**.*

For more than a century, scientists and engineers have worked to overcome the natural resistance of biomass to chemical and/or biological degradation. The body of research in this area, which is often highly empirical in nature, has led to improvements in yield and cost of accessing the sugars. This empirical approach, however, is not good enough to meet the kind of aggressive performance requirements needed to compete with petroleum. The leap to this level of competitive technology will require delving into the fundamentals of biomass structure and its effects on chemical and biological hydrolysis; and the interaction between biomass and chemical and biological catalysts,

- *Limited understanding of the potential for **alternative conversion technology pathways**.*

Making the leap from technology that can compete in niche or marginal markets for fuels and products also requires expanding the array of possible concepts and strategies for processing biomass. Concepts such as consolidated bioprocessing, in which the hydrolysis and conversion of carbohydrates to products is done using a single organism, offer new possibilities for leapfrog improvements in yield and cost. New concepts are likely to arise from the advances in fundamental understanding of biomass and its hydrolysis.

- *Lack of fundamental **enabling technology tools***

Much more work is needed to develop a comprehensive list of these fundamental barriers.

The Office of the Biomass Program uses technoeconomic analysis as a tool to judge the relative cost impacts of addressing these technical barriers for a given technology. An example of such an analysis for a number of the critical barriers identified in the emerging sugar platform based on enzymatic hydrolysis

technology is shown in Figure 2. In this case, analysis examined the impact of progress on the following barriers:

- Feedstock Interface: Cost of feedstock reduced from \$40 to \$30 per dry ton. This or another goal would be better stated in terms of ethanol potential per ton of biomass.
- Pretreatment: Increase yields of hemicellulosic sugars from demonstrated level of 60-70% to 80%
- Pretreatment: Decrease pretreatment systems capital cost by 25-50%.
- Enzymatic Hydrolysis: Reduce the cost of enzyme from \$0.64 to \$0.10 per gallon of ethanol
- Strains: Achieve high yields of ethanol from all sugars

As indicated in Figure 12, the cumulative effect of achieving these targets in all of the barriers provides approximately 50% savings in the cost of ethanol relative to the experimentally verified performance of the technology in FY 2003.

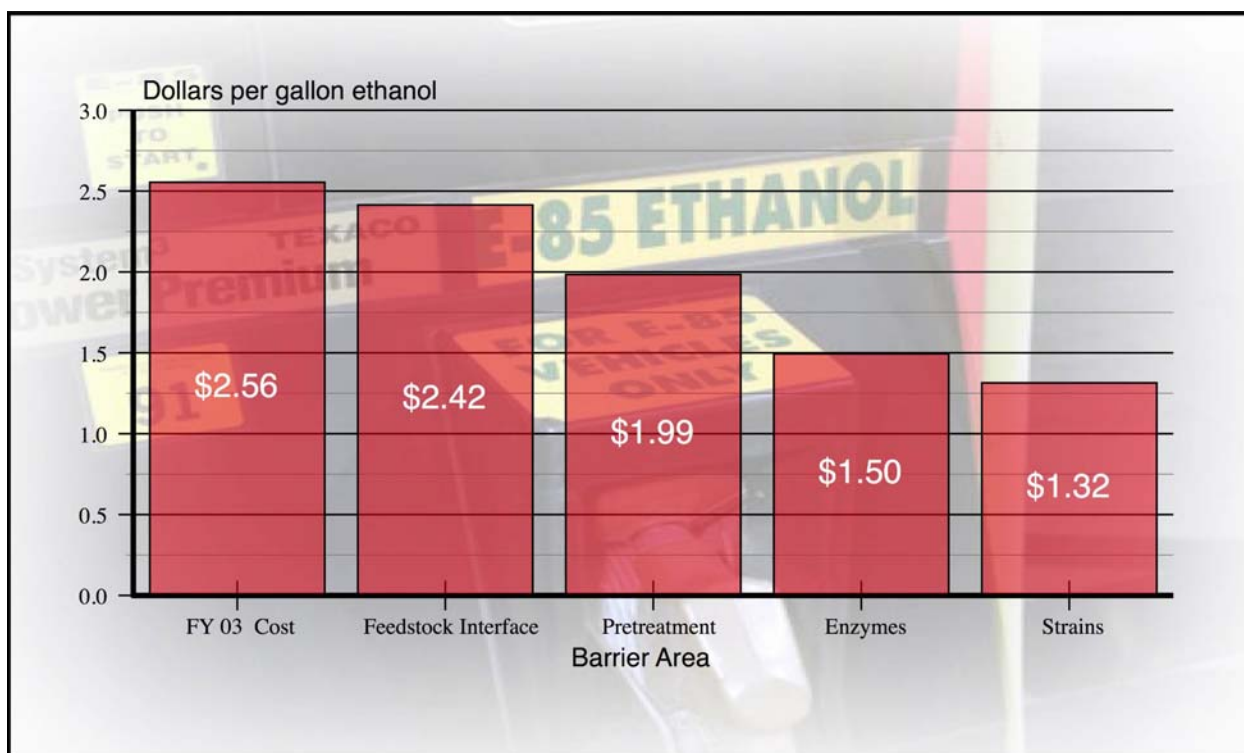


Figure 12: Translating Reductions in Technical Barriers to Cost Savings for the Sugar Platform

2.2.4 Technical Approach

The core research for the sugar platform is organized in terms of the barriers described in the previous section. These barriers, as previously discussed, can be grouped in terms of those related to existing and emerging biorefinery development and advanced (long term) biorefinery development. The timing of the core research and development activities related to existing and emerging biorefinery technology is constrained by the timing of industry-led projects aimed at deploying these technologies. In the language of stage gate management, the integrated biorefinery projects being developed by industry are

“commercial line” activities, while the technical barrier work directly addressed by the program are “research line” activities. This relationship is shown in the Pert chart in Figure 13.

Commercial line activities are already underway in the program, each with the goal of addressing specific opportunities for translating emerging technology into commercial integrated biorefineries or utilizing new technology components in existing biorefineries. As these projects move through process development (stage 3) and into a commercial demonstration (stage 4), they can take advantage of the ongoing core R&D that continues in parallel with them. Obviously, the window of opportunity timeframe for R&D focused on emerging technology becomes more and more constrained as the commercial line projects approach final deployment. Beyond that point, some research can continue on incremental improvements to the new commercial technologies, but this is more likely to be done by industry.

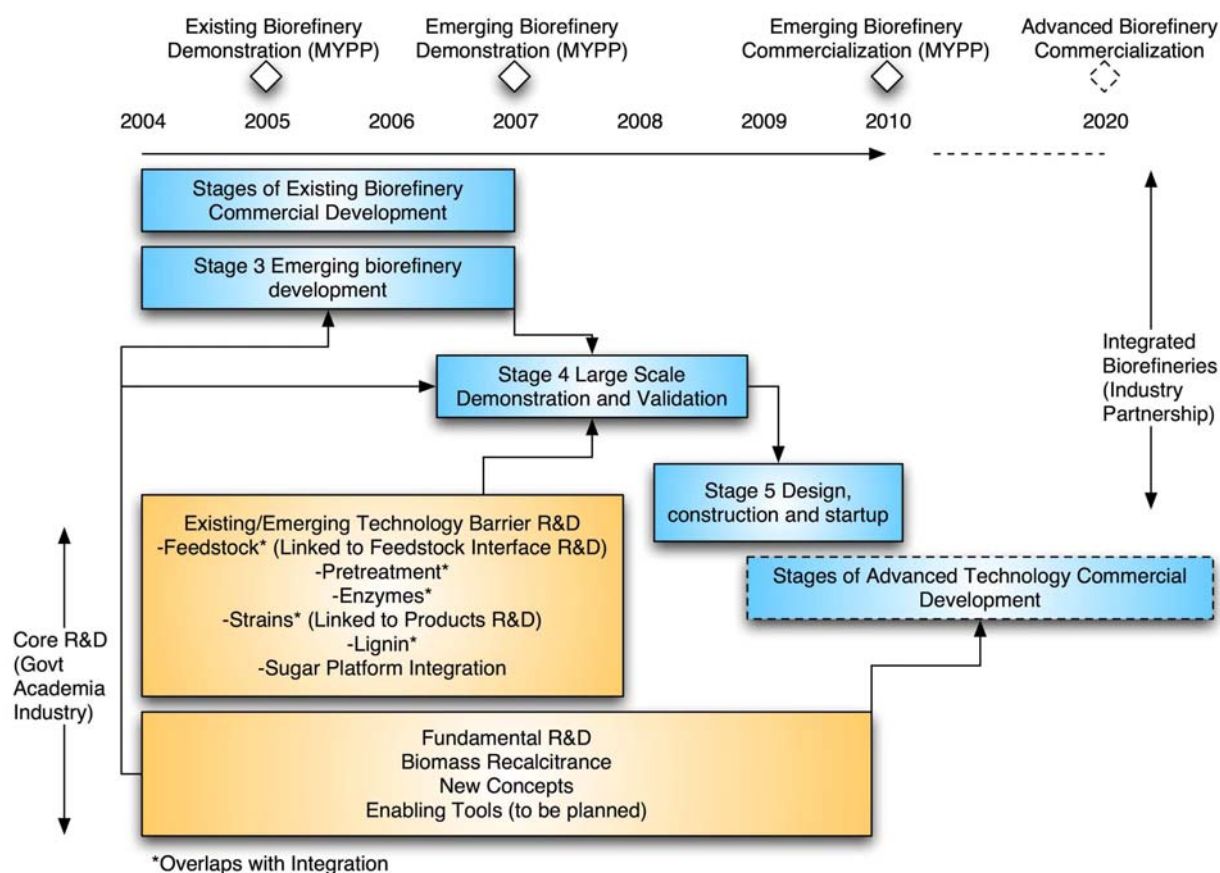


Figure 13: Relation of Sugar Platform Core R&D to Integrated Biorefinery Activities

The commercial line projects drive the timing of many of the major outcomes for the program. Although a better enzyme preparation or a more efficient fermentation strain may be expected to integrate well into a previously designed or constructed facility, substantial changes in pretreatment chemistry or process integration insights might be expected to require expensive retrofits. The existing biorefinery projects support the goal of demonstrating the key technology components of pretreatment and enzymatic hydrolysis in existing corn grain processing facilities in 2005. One or more of the industrially led partnerships established as part of the program’s bioenergy solicitation conducted in FY 2002 will lead to the program’s two other important outcomes for the sugar platform—demonstration (in 2007) and commercialization (in 2010) of technology capable of producing low cost sugars.

Research on advanced technology—longer term and higher risk approaches—must begin today. Thus, this multi-year technical plan for the sugar platform includes research activities that address the more fundamental scientific and engineering issues that face the sugar platform if it is to play a role in our long-term energy supply. By focusing on the fundamental causes of biomass recalcitrance, the development of new tools for technology development, and the development and evaluation of new process concepts, these advanced R&D projects will lead to the next generation of technologies that will feed into the commercial development pathway. The timing of this work is inherently less clear than that of the emerging technology projects.

The work breakdown structure shown in Figure 14 translates the core R&D strategy outlined here into a working organization of focused projects. The core R&D effort for the sugar platform is broken down into five distinct projects. The first three projects directly address three of the existing/emerging technology barriers (pretreatment, enzymes, and process integration). The process integration project includes some limited work on the barriers related to feedstock variability and lignin utilization. The Fractionation Fundamentals and Advanced Concepts project addresses all of the advanced barriers related to understanding the recalcitrance of biomass and developing new concepts for processing of biomass sugars.

Not all of the technical barriers related to the sugar platform fall neatly within the bounds of this program area. In the work breakdown structure shown in Figure 14, we indicate linkages between the sugar platform core R&D area and the areas of feedstocks, products from sugars, and commercial line integrated biorefinery projects. The work on feedstocks described in the Feedstock Interface R&D has very close ties with the research done directly in support of the sugar platform elements and their integration. Perhaps the most significant crossover occurs between the Products R&D area and the Sugar Platform core R&D. In the case of the sugar platform, it is impossible to separate work done on catalysts for converting sugars from the platform technology used to produce the sugars. The separation between sugars production and conversion of sugars to products is an artificial one, which could—if not managed carefully—lead to disconnects in the development of each aspect of the technology. In fact, the physical distinction in process steps between sugar production and conversion of sugar to products often times does not exist, since enzymatic hydrolysis and conversion can occur simultaneously. Finally, the line between core R&D and the commercial development of an integrated sugar biorefinery is also hard to draw. Some amount of integration work is critical as part of the development of individual process steps, since it is the integrated performance of these individual steps that really count. Thus some amount of product related work will occur as part of the core R&D. In the sugar platform, partly because of the program's history and partly because fuel production is central to the program, we use ethanol production as a reference product for conducting integrated process research. In the end, however, each biorefinery project will face its own specific set of integration issues that are dictated by the specific feedstock, process configuration and product slate associated with it.

2.2.4.1 Existing and Emerging Sugar Biorefineries

The following briefly summarizes the strategies that underlie each of the three projects that address the technical barrier areas of pretreatment, enzymes and process integration.

2.2.4.1.1 Pretreatment

More than 20 years of research have gone into developing pretreatment technologies for enzyme based hydrolysis processes. The emphasis of our work on pretreatment is, therefore, on evaluation of and improvements to the leading pretreatment concepts that have surfaced during this period. A Gantt chart describing the pretreatment R&D planned to support the existing and emerging biorefinery efforts over the next five years is shown in Figure 16. The program leverages the work of the Biomass Refining Consortium on Applied Fundamentals and Innovation (CAFI), a group of pretreatment researchers funded by the USDA and recently selected for continued funding in the FY03 USDA/DOE solicitation.

Technoeconomic evaluations of competing pretreatment concepts will be done in two stages, based on the best available data on the performance of each technology. By the end of 2007, consistent comparative data of the top three to five most promising concepts will be available for review by industry partners facing critical technology choices prior to entering the commercial demonstration for their specific emerging sugar biorefinery projects. At the same time, the program will seek opportunities to explore evaluation of near-term pretreatment technologies in existing corn grain dry mills. Adoption of lignocellulose-specific pretreatment technologies provides a way of releasing additional sugars from fiber in the grain and thus offers a means of accelerating commercial experience with these technologies. Finally, the program will support some linking research on the effect of different biomass storage and preprocessing strategies on the performance of pretreatment and subsequent enzymatic saccharification.

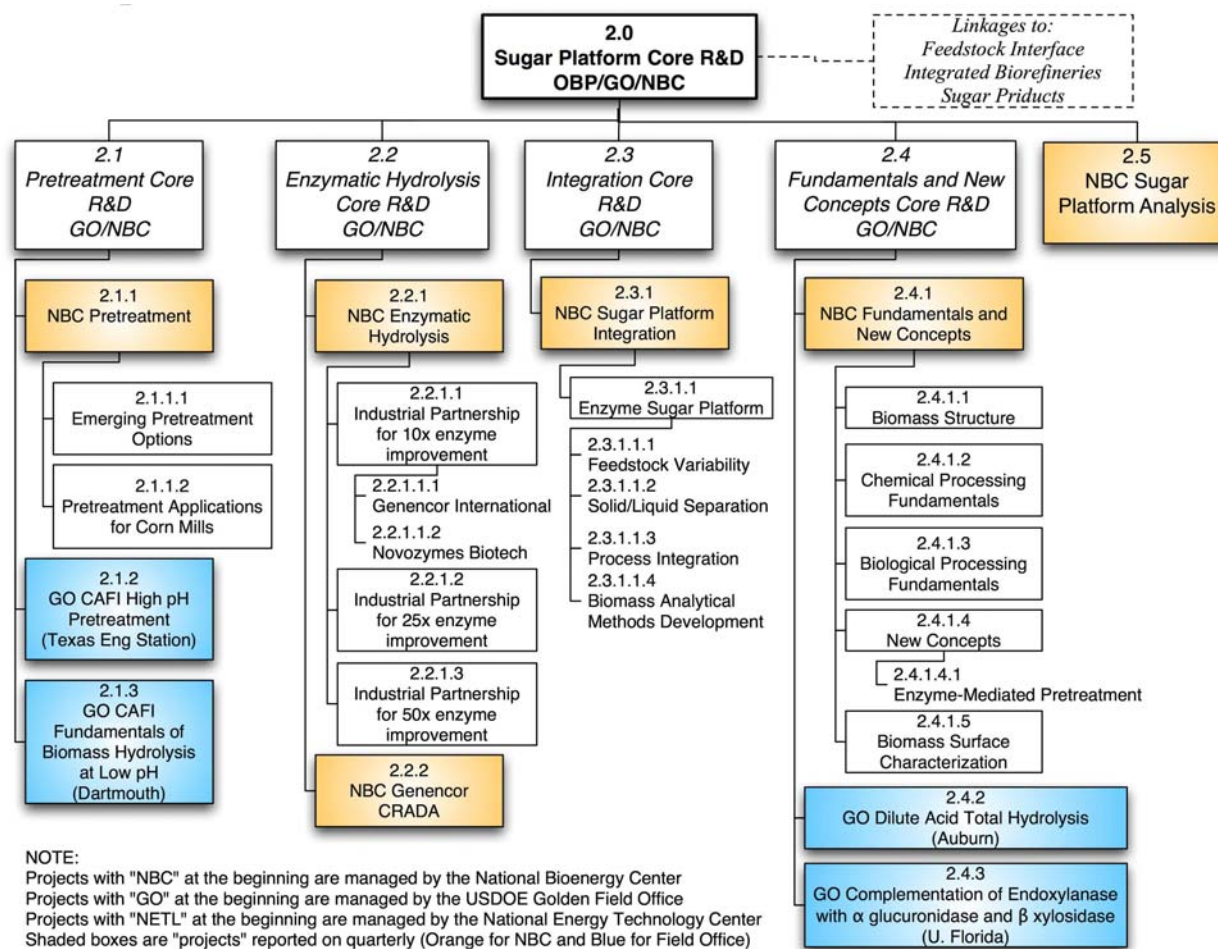


Figure 14: Work Breakdown Structure for the Sugar Platform Core Barrier R&D

2.2.4.1.2 Enzymes for Cellulose Hydrolysis

Figure 17 presents the detailed activities of the Program that address the need for more cost effective enzymes to hydrolyze cellulose. Our strategy for the near-term work on reducing the cost of cellulose hydrolyzing enzymes is to cost share and technically support continued enzyme cost reduction efforts by DOE's industrial enzyme partners, Genencor and Novozymes. The current projects led by these two companies have led to the potential to reduce enzyme costs to around \$0.30-0.50 per gallon of ethanol for an integrated process in which sugars produced by pretreatment and enzymatic hydrolysis of corn stover are converted to ethanol by genetically modified fermenting bacteria. Provided cost share funding continues, both companies are expected by 2005 to have developed a clear route to a final cost of

\$0.10/gallon ethanol or less by the 2010 commercialization timeframe. Data from further development and evaluation of these 2nd generation enzymes should be sufficiently complete to support decisions by industrial partners preparing to make critical technology choices for commercial demonstration of their specific emerging sugar biorefinery projects.

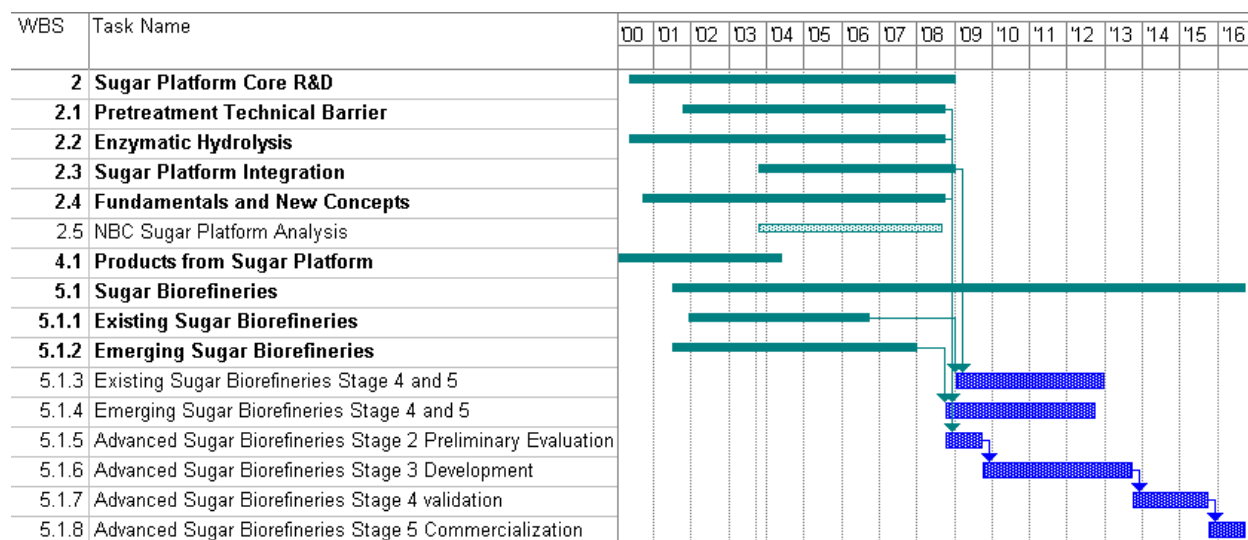


Figure 15: High Level Gantt Chart View of All of the Sugar Platform Related Activities in the MYTP

2.2.4.1.3 Process Integration in Support of Emerging Biorefineries

Figure 18 shows the detailed activities planned as part of our effort to address the barrier of iintegration. Our approach focuses on integrating enzymatic hydrolysis process technology based on dilute acid pretreatment that incorporates the advanced, lower-cost cellulase enzymes being developed by Genencor and Novozymes with DOE cost-share. The major milestone is to complete a limited pilot scale demonstration of integrated processing and to use the process performance data to validate (or update) process economic modeling assumptions by 2006. Interim milestones are: 1) demonstrate reliable compositional analysis methods and accurate pretreatment yield measurement (defined as achieving a C-balance closure of 95% across pretreatment) by 2004; 2) achieve high-yield high solids pretreatment (defined as 85% hemi yield and 90% enzymatic digestibility at 30% solids) by 2005; 3) Demonstrate integrated processing in 2006, with the minimum goals here being to run the process for 1 week (24/7) at the 1 ton/day process scale. Finally, as part of linkage between the sugar platform core R&D and the Feedstock Interface R&D, the program will evaluate the factors underlying corn stover compositional variability, with an eye toward strategies that minimize or otherwise exploit this variability. A small effort will be undertaken to validate the combustion value of lignin residues resulting from integrated process testing. Underlying all of this work is the continued development of rapid analysis techniques that support the ability to generate timely mass balance data.

2.2.4.2 Fractionation Fundamentals and Advanced Concepts

Figure 19 shows the planned Program activities for fundamentals and new concepts/The goal of the research for advanced sugar biorefineries is to develop a more fundamental and deeper understanding of the factors and causes underlying the recalcitrance of biomass to biological and chemical degradation. Research on biomass recalcitrance is broken down into research on biomass ultrastructure and micro-scale chemistry, fundamentals of biologically-based biomass fractionation and fundamentals of chemically-based biomass fractionation. Embodied in much of this work is the development of enabling tools, such as molecular modeling simulations and more accurate and sensitive chemical and structural

analysis techniques for characterizing biomass materials at various stages during processing. The Sugar Platform Analysis project captures process engineering and life cycle analysis needed to direct the research by translating all of the proposed and actual outputs from research into quantifiable costs and benefits for the technology.

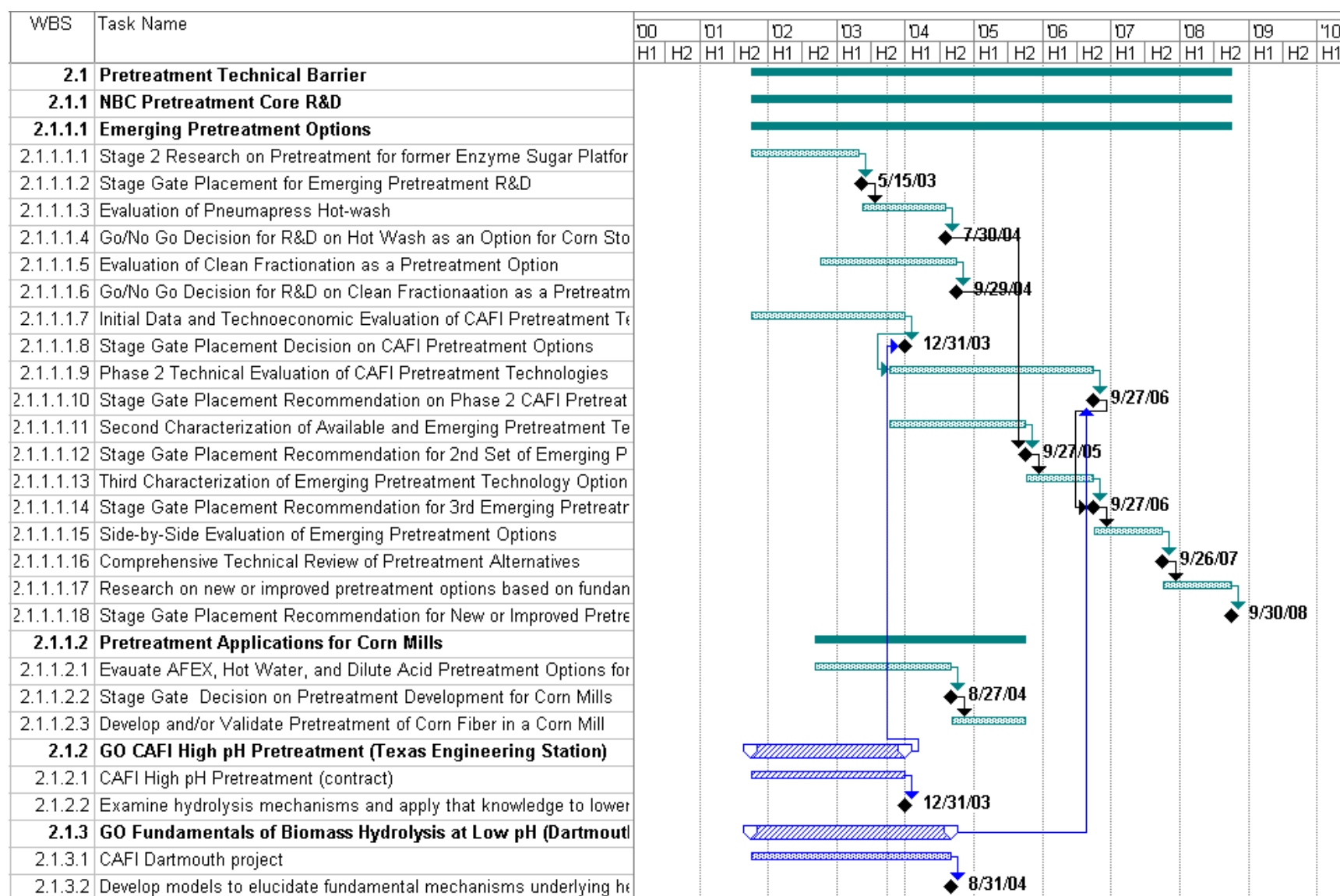


Figure 16: Biomass Program Activities Addressing the Pretreatment Barrier for Emerging Bio refineries

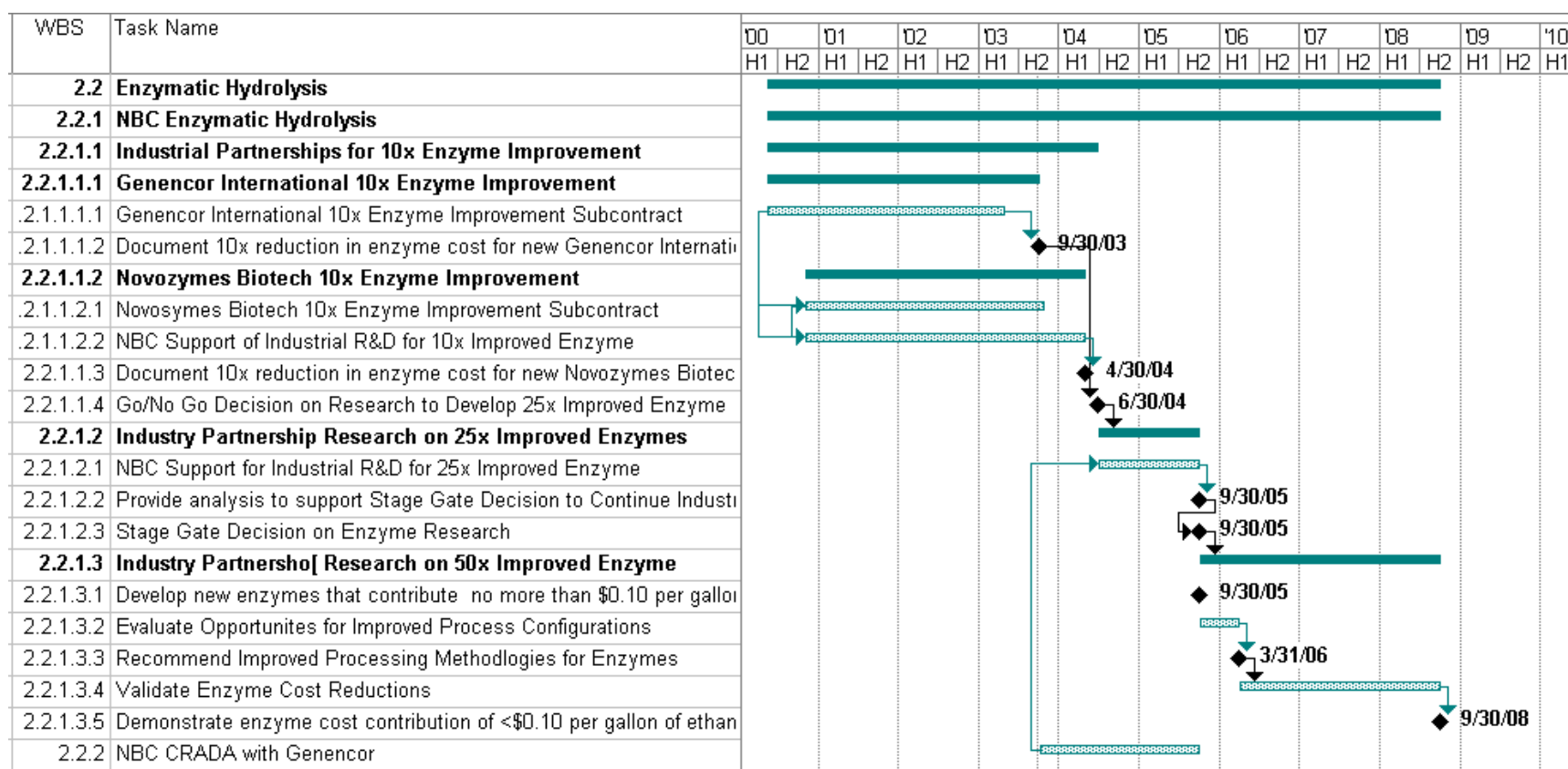


Figure 17: Biomass Program Activities Addressing the Enzyme Barrier for Emerging Bioerfineries

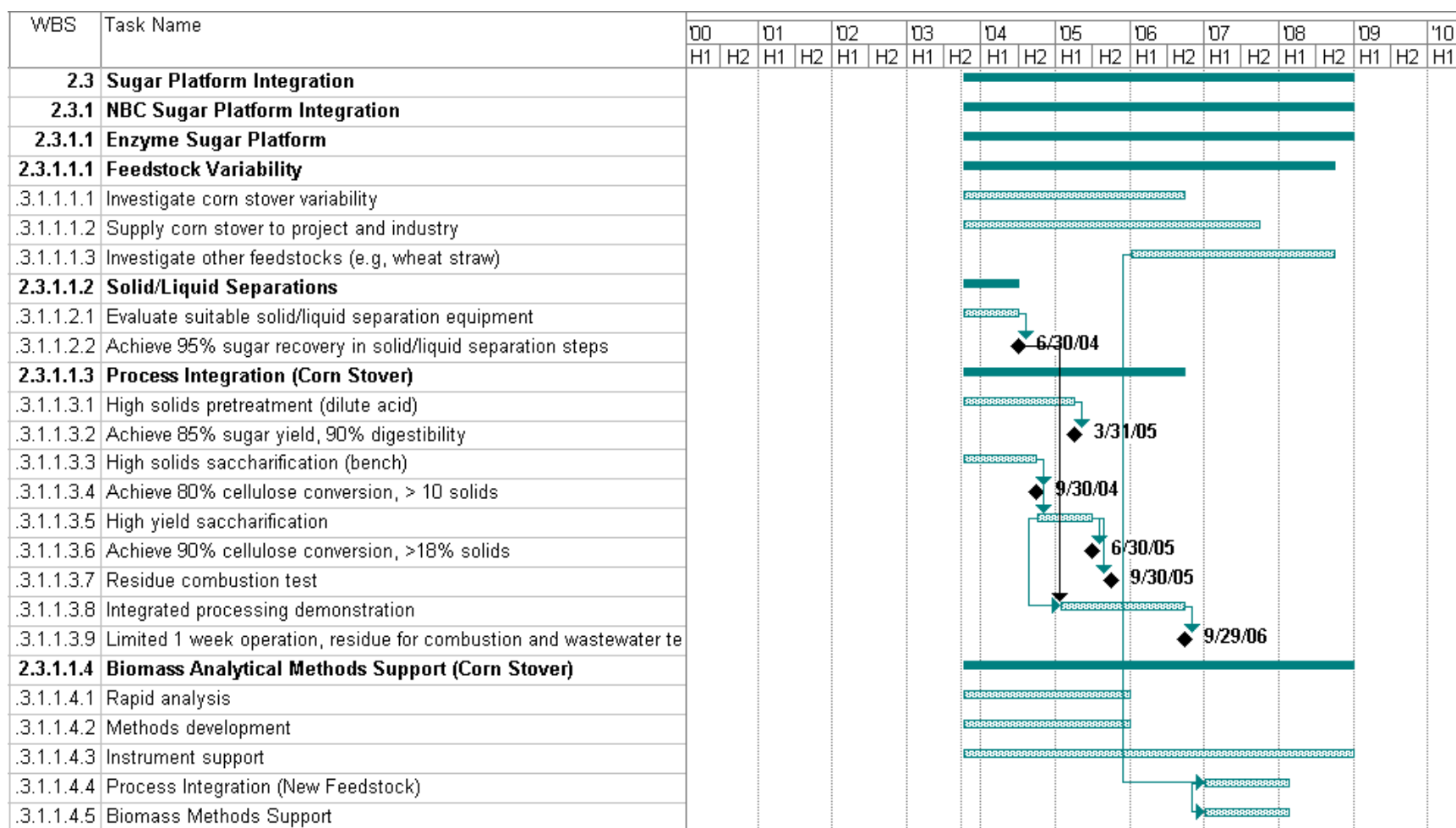


Figure 18: Biomass Program Activities Addressing the Process Integration Barrier for Emerging Sugar Biorefineries

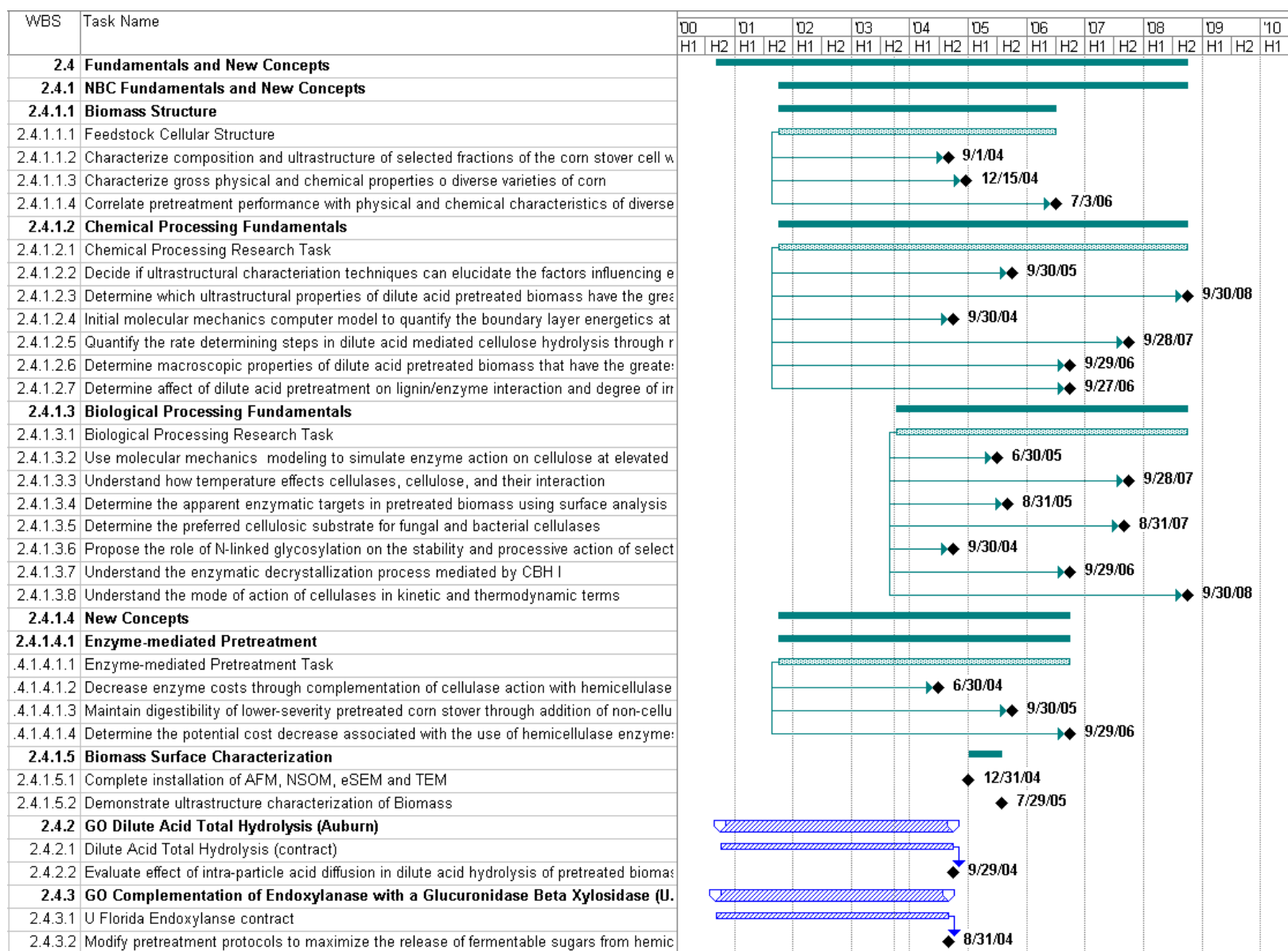


Figure 19: Biomass Program Activities Addressing the Fundamental Barriers for Emerging and Advanced Sugar Biorefineries

2.2.4.3 Sugar Platform Analysis Support

Analysis is performed under this task to support the on-going research in the sugar platform. Analysis helps to provide direction and focus to the research by evaluating the technical, economic, and environmental aspects of biomass sugar production and conversion. This analysis also supports OBP's goals and feeds into the Multi-Year Analysis Plan (MYAP).

Much of the analysis work to be done is a continuation and elaboration of past efforts to model and understand the economic factors and key uncertainties related to the sugars route to ethanol from lignocellulosic biomass. The process to produce ethanol will still be used as a base case process to evaluate the economic impacts of technology developments. However, increasingly greater emphasis will be given to the production of additional products from the sugar streams in addition to ethanol.

2.2.5 Resource Allocation Plan

Figure 20 and Table 3 provide a high level summary of the proposed costs for projects included in the sugar platform core R&D area of the program.

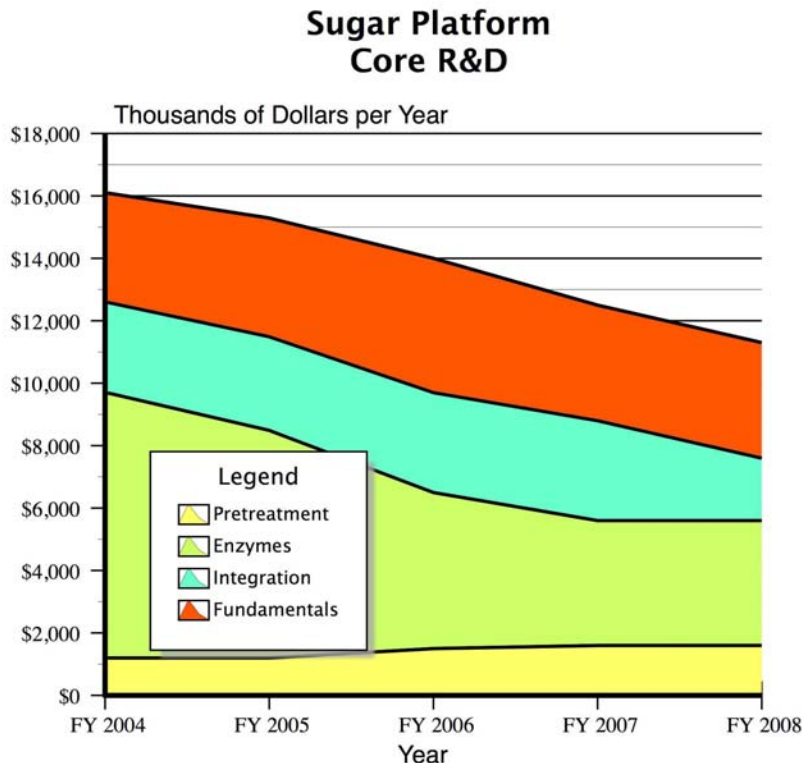


Figure 20: Sugar Platform Core R&D Resource Plan

2.2.6 Overview of Projects and Milestones

Table 4 summarizes all of the projects that support core R&D for the sugar platform, along with their major milestones (or outputs). The projects are organized into the technical barrier areas identified previously. For each project, we have identified technical barriers specifically addressed within the broader technical barrier.

Table 3: Sugar Platform Core R&D Resource Plan

WBS	Title	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
2	Sugar Platform Core R&D		\$497	\$702	\$388	\$16,201	\$15,290	\$14,000	\$12,500	\$11,300
2.1	<i>Pretreatment Technical Barrier</i>		\$497	\$497	\$277	\$1,200	\$1,200	\$1,500	\$1,600	\$1,600
2.1.1	NBC Pretreatment Core R&D					\$1,200	\$1,200	\$1,500	\$1,600	\$1,600
2.1.1.1	Emerging Pretreatment Options					\$1,100	\$1,050	\$1,500	\$1,600	\$1,600
2.1.1.2	Pretreatment Applications for Corn Mills					\$100	\$150	\$-	\$-	\$-
2.1.2	GO CAFI High pH Pretreatment (Texas Engineering Station)		220	\$220						
2.1.3	GO CAFI Fundamentals of Biomass Hydrolysis at low pH (Dartmouth)		277	\$277	\$277					
2.2	<i>Enzymatic Hydrolysis</i>					\$8,490	\$7,290	\$5,000	\$4,000	\$4,000
2.2.1	NBC Enzymatic Hydrolysis					\$8,200	\$7,000	\$5,000	\$4,000	\$4,000
2.2.2	NBC CRADA with Genencor					\$290	\$290			
2.3	<i>Sugar Platform Integration</i>			\$-	\$-	\$2,900	\$3,000	\$3,200	\$3,200	\$2,000
2.3.1	NBC Sugar Platform Integration					\$2,900	\$3,000	\$3,200	\$3,200	\$2,000
2.4	<i>Fundamentals and New Concepts</i>			\$205	\$111	\$3,611	\$3,800	\$4,300	\$3,700	\$3,700
2.4.1	NBC Fundamentals and New Concepts		0	\$-	\$-	\$3,500	\$3,800	\$4,300	\$3,700	\$3,700
2.4.1.1	Biomass Structure					\$500	\$500	\$600		
2.4.1.2	Chemical Processing Fundamentals					\$700	\$800	\$800	\$900	\$900
2.4.1.3	Biological Processing Fundamentals					\$1,300	\$1,500	\$2,000	\$1,900	\$1,900
2.4.1.4	New Concepts					\$500	\$500	\$600	\$600	\$600
2.4.1.4.1	Enzyme-mediated Pretreatment									
2.4.1.5	Biomass Surface Characterization					\$500	\$500	\$300	\$300	\$300
2.4.2	GO Dilute Acid Total Hydrolysis (Auburn)		94	\$94						
2.4.3	GO Complement Endoxylanase w/ Glucuronidase β Xylosidase (U. FL)		111	\$111	\$111	\$111				

Table 4: Alignment of Projects and Milestones in the Sugar Platform Core R&D Area

Biomass Program Goal: To develop the capability for using lignocellulosic biomass to produce inexpensive sugar streams that can be utilized for the production of fuels, other chemicals and materials.

Objective: By 2010 reduce the cost of a mixed, dilute sugar stream suitable for fermentation to ethanol, in a mature biochemical plant, from \$0.14 per lb in 2003 to \$0.07 per lb.

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
Pretreatment GO/NBC	2.1.1 Pretreatment	<ul style="list-style-type: none">• Lack of experience with pretreatment as an option for releasing hemicellulosic sugars in existing corn grain processing.• Lack of consistent, comparative technical characterization of emerging technology options• Lack of consistent economic evaluation of emerging pretreatment technology options	08/2004: Comparative evaluation of AFEX and dilute acid/hot water pretreatment of corn fiber 09/2007: Technical review of pretreatment alternatives
Enzymes GO/NBC	2.2.1 Enzyme Hydrolysis	<ul style="list-style-type: none">• Low reactivity of current commercial enzymes.• High cost of enzyme production.• Enzyme biochemistry.• Process integration	03/2004: Novozymes biotech achieves ten fold cost reduction for cellulase in ethanol production 09/2008: Validate performance of \$0.10/gallon ethanol new generation cellulase enzymes
Fermentation (Existing and Emerging Technology Applications)	See projects in the “Products” area	<ul style="list-style-type: none">• See projects in the “Products” area 4.1.1.2.1 Arabinose Yeast CRADA, 4.1.1.2.2, Ethanologen Research 4.1.2 GO Develop Yeast for Chemicals (Cargill Dow Polymers)	See projects in the “Products” area of the plan (Table 17)

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
Integration GO/NBC	2.3.1 Sugar Platform Integration	<ul style="list-style-type: none"> • Unproven use of residues for combustion, heat and power. • Unproven integrated performance of high solids processing (30% in pretreatment, 20% in saccharification) anticipated for large scale operations 	<p>09/2005: Validate combustion of process residues for heat and power generation</p> <p>9/30/06: Integrated pilot-scale demonstration, 24/7 for one week, pretreatment, saccharification, fermentation, at high solids.</p> <p>09/2008: Validate integrated pretreatment, saccharification and fermentation of biomass using improved enzymes and fermentation organisms</p>
Fundamentals and New Concepts GO/NBC	2.4.1 NBC Fundamentals and New Concepts	<ul style="list-style-type: none"> • Biomass Structure. • Chemical processing fundamentals. • Biological processing fundamentals. • Conversion concepts. 	<p>09/2004: Proof-of-concept for consolidated bioprocessing (CBP) via heterologous cellulase expression (Dartmouth)</p> <p>12/2004: Demonstration of ultrastructural characterization of biomass samples</p> <p>09/2005: Determine whether noncellulase enzymes can reduce required pretreatment severity.</p> <p>07/2006: Achieve a better understanding of the physical, chemical and ultrastructural features of corn plants that affect process performance.</p> <p>09/2007: Understand how temperature effects cellulases, cellulose, and their interaction.</p> <p>09/2008: Determination of ultrastructural properties of pretreated biomass with impact on cellulase susceptibility.</p>
NBC Sugar Platform Analysis	2.5 Analysis Support of the Sugar Platform	<ul style="list-style-type: none"> • Linkage between research goals and economic and environmental impacts 	On going life cycle and technoeconomic analysis

2.3 The Thermochemical Platform

The Thermochemical Platform involves the use of elevated temperature to convert biomass or biomass-derived biorefinery residues to intermediates that may be used directly as raw fuels or products, or that may be further refined to produce fuels and products that are interchangeable with existing commercial commodity products. Intermediate products include clean syngas (a mixture primarily of hydrogen and carbon monoxide), pyrolysis oil, hydrothermal oils, and gases rich in hydrogen or methane. These intermediate products can be used directly for heat and electric power generation, or may be upgraded by various processing technologies to products such as crude oil, gasoline, diesel, alcohols, olefins, oxochemicals, synthetic natural gas or high-purity hydrogen.

Gasification and pyrolysis both involve the conversion of solid or liquid organic matter to gases (CO , CO_2 , H_2 , and CH_4), organic vapors, water, and residual solids at elevated temperature. A strict technical definition is that pyrolysis takes place through the application of elevated temperatures in the absence of any reactive compounds or oxidants. Gasification is the reaction of any carbonaceous feedstocks with air, oxygen, steam, carbon dioxide, or mixtures of these, to yield a gaseous product that is suitable for use either as a source of energy or as a raw material for the synthesis of chemicals, liquid fuels, or other gaseous fuels. A practical definition that covers most biomass conversion processes states that the primary difference between pyrolysis and gasification is that pyrolysis takes place at temperatures (ca. $400 - 650^\circ\text{C}$; $750^\circ\text{F} - 1,200^\circ\text{F}$) where the primary product is a liquid (pyrolysis oil), while gasification takes place at higher temperatures (ca. $650 - 900^\circ\text{C}$; $1,200^\circ\text{F} - 1,650^\circ\text{F}$) where the primary products are permanent gases (CO , CO_2 , H_2 , CH_4). A third term seen frequently is steam reforming. In the context of the thermal conversion of solid biomass, this refers to high temperature ($650 - 900^\circ\text{C}$; $1,200^\circ\text{F} - 1,650^\circ\text{F}$) pyrolysis (absence of oxygen) in the presence of steam to produce primarily permanent gases.

A third alternative (apart from gasification and pyrolysis) is hydrothermal processing with excess amounts of water and/or organic solvent at medium temperatures ($300 - 350^\circ\text{C}$; $570 - 660^\circ\text{F}$) and sufficient pressure (16 MPa; ca. 2,300psia) to maintain the water or solvent in the liquid phase. The primary products are complex hydrocarbon liquids including long aliphatic chains, some cyclic compounds containing carbonyl groups, and a few hydroxyl groups, ether linkages, and carboxylic acid groups. Hydrothermal processing in the presence of a heterogeneous catalyst, e.g. Ni-Ru, produces primarily methane or hydrogen and is referred to as wet gasification.

Thermochemical conversion provides an efficient approach for producing fuels and products from a wide variety of biomasses. Thermal processes readily converts all major components of biomass including lignin, which is currently resistant to biological conversion, to intermediate building blocks. Utilization of the lignin, which is typically 25-30% of the biomass, is essential to achieve high efficiencies in the biorefinery. Thermal processes are "omnivorous" in this regard and can convert most biomass feedstocks or residues to a raw synthesis gas. In the case of gasification cleanup and conditioning of the raw gas, results in a clean synthesis gas. It is then possible to access and leverage the extensive process technology developed in the petroleum and chemicals industry to produce a wide range of liquid fuels and chemicals.

Biomass gasification is important in providing a source of fuel for electricity and heat generation for the integrated biorefinery. Virtually all other conversion processes, whether physical, chemical, or biological, produce residue that aren't currently or can't be converted to the primary product(s). To avoid a waste stream from the refinery and to maximize the efficiency of the biorefinery, these residues can be used for combined heat and power production (CHP). In existing facilities, these residues are combusted to produce steam for power generation. Gasification offers the potential to utilize higher-efficiency power generation technologies such as combined cycle gas turbines or, in the future, fuel cells. Gas turbine systems offer potential electrical conversion efficiencies approximately double that of steam-cycle processes, with fuel cells being nearly 3 times as efficient.

2.3.1 Technical Goals and Objectives

The overall goal of the Thermochemical Platform is to reduce our dependence on foreign oil and to stimulate the rural economy by using thermal processing to produce fuels, chemicals, hydrogen, and heat and power from a range of biomass feedstocks.

In the shorter term, it is the objective of the Thermochemical Platform to ensure that biomass gasification technologies are compatible with the production of fuels and chemicals based on technologies currently available through the petroleum industry. This will provide nearer-term opportunities for biomass while also leveraging the extensive related experience of industry. In the mid to longer term, the objective of the Platform is to ensure that biomass syngas technologies are compatible with advanced utilization technologies. These will include hydrogen-related technologies as well as advanced utilization technologies better suited to the scale at which biomass is available. These development efforts will directly support and contribute to achieving the hydrogen-from-biomass targets set by the Office of Hydrogen, Fuel Cells and Infrastructure Technologies (OHFCIT) (\$2.60/kg H₂ from biomass gasification and \$2.90/kg H₂ from pyrolysis by 2010).

Both program offices (OBP and OHFCIT) have identified many of the same barriers to success: (improved gasification, better feedstock handling, improved gas and pyrolysis oil cleanup and conditioning. Ref. "Hydrogen, Fuel Cells and Infrastructure Technologies Program, Multi-year Research, Development and Demonstration Plan" pp. 3-12, 3-18).

A further objective of the Thermochemical Platform is to develop reliable gasification-based combined heat and power systems for integration with all types of biorefineries. These gasification technologies will include those for "conventional" biomass and biomass residues as well as for black liquor. It is important to determine the scales and applications at which biorefineries are economic and will be developed and to have appropriate gasifier systems available at those scales. The Platform will address both shorter-term technologies such as gas turbines as well as longer-term options such as advanced fuels cells.

The Thermochemical Platform also addresses other thermochemical conversion approaches, particularly pyrolysis and hydrothermal gasification. Pyrolysis converts biomass primarily to liquid products, with smaller amounts of syngas and char also being produced. The liquid "biocrude" is superficially similar to fuel oil but is chemically quite different. Like gasification, pyrolysis of "omnivorous" and converts all major fractions of the biomass resource. The liquid can be used as an intermediate to produce fuels, products, or electricity. The relatively high energy density of the pyrolysis liquids also potentially allows them to be economically transported to a central site for processing into fuels and chemicals. In this area, the objectives of the Platform are to ensure that the liquid and gaseous products from pyrolysis products can successfully be utilized in a thermochemically-based biorefinery.

In certain areas of the Thermochemical Platform, it may be possible to leverage efforts, developments, and accomplishments from the Office of Fossil Energy (FE). This is most likely in the areas of gas cleanup and conditioning. Coal gasifiers have generally been developed for much larger scale operation and a feedstock that is physically and chemically very different from biomass. In fact, the most widely applied commercial coal gasifiers all use a coal slurry feed, an approach that is not feasible with biomass from an energy and efficiency perspective.

2.3.2 Programmatic Status

The Thermochemical Platform was started in FY2003 with the development of a multi-year program plan that forms the basis of this multiyear technical plan. The program is in a transitional phase moving from an emphasis on power systems to an emphasis on fuels and chemicals systems. Since the Thermochemical Platform is a new effort in its first year the effort involves existing projects at the National Laboratories, NETL, the Golden Field Office (GO) and with existing subcontractors. Some of

these “legacy” projects may represent a good fit with new program priorities; however, this will be the subject of investigation and alignment in FY04.

The existing efforts include:

Thermochemical Processing

- Wet gasification (performed by PNNL using a modular reactor system),
- Congressionally mandated research projects managed by the DOE Golden Field Office at the Southern Research Institute (SRI)/Gas Research Institute (GTI) and at Iowa State University (ISU)
- Fuel chemistry and bed performance in a black liquor reformer (University of Utah)

Cleanup and Conditioning

- Continuation of laboratory efforts in gas cleanup and conditioning with an emphasis on catalytic tar cracking (performed at NREL using Ni based catalysts in a 2” reactor and with an 8” fluid bed reactor that will be installed by December 2003),
- Evaluation of RVS-1 sorbent for removal of sulfur from black liquor gasification (NETL)

Thermochemical Platform Analysis

- Preliminary technoeconomic analyses of fuels and chemicals synthesis processes (performed by NREL)

Containment

- Black liquor gasification materials support R&D placed via competitive solicitation and managed by NETL

Products-related projects (discussed in Section 2.4 of this document)

- Completion of laboratory investigations of the use of syngas for electricity generation in internal combustion engines and microturbines (performed at NREL using an electrically-heated gasifier at the 15-20 kWe scale)
- Initiation of investigations for the use of syngas in fuels cells (performed at NREL using a 5 kW SOFC fuel cell)
- Pyrolysis oil upgrading (performed by PNNL using Ru catalysts in batch experiments)
- Fuels synthesis in microchannel reactors (performed by PNNL using existing reactors),
- Initiation of evaluations of the suitability of syngas as a catalytic synthesis feed (performed at NREL in a fixed-bed microreactor)

Integrated Biorefinery-related projects (discussed in Section 2.5 of this document)

- Carbona Corporation, gasification based CHP (5.4 MWe, 11 MWt) using a fluid bed gasifier, catalytic tar cracking, and internal combustion engines
- Community Power Corporation, gasification based CHP (15 kWe) using a downdraft gasifier, particulate separation and internal combustion engines
- Flex Energy, gasification/anaerobic digester gas/landfill gas use in a catalytic microturbine
- Georgia-Pacific Corporation full-scale demonstration of black liquor gasification at the Big Island pulp and paper mill

2.3.3 Technical Barriers

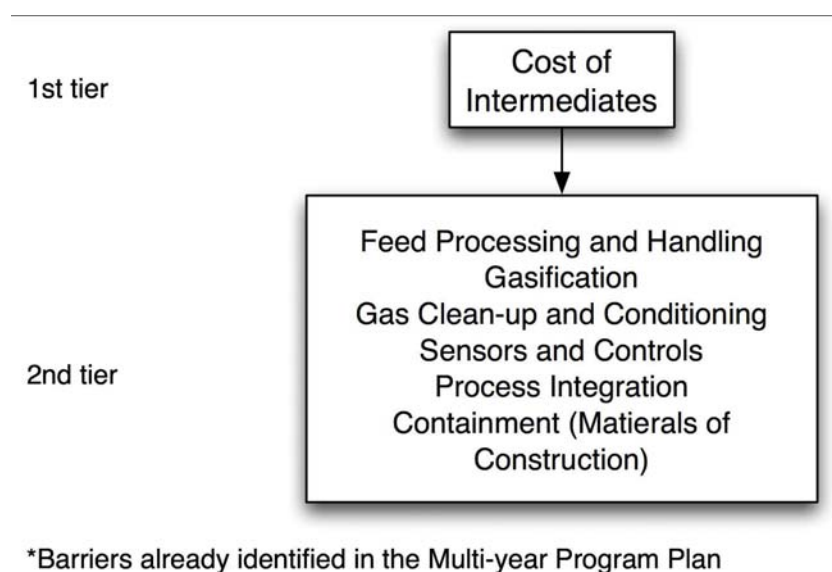
As with the sugar platform, the overarching barrier to deployment of the syngas platform is its inability to compete with fossil fuel in almost all applications. We have identified a number of barriers that contribute to the cost barrier, as shown in Figure 21.

The specifics of these barriers and the proposed approaches for addressing them are discussed below.

Prioritization Process

Realizing the complexity of the task to provide the best technical support program within the constraints of limited resources, a number of experts from the industry, academia and the national laboratories were asked to take the results of technology summit session and develop a prioritized list of needed information that aligned with a focused set of program areas.

The major barrier areas, their relative priority and potential cost reduction impact are listed in Table 5.



*Barriers already identified in the Multi-year Program Plan

Figure 21: The Hierarchy of Barriers to the Deployment of Thermochemical Platform Technology

Table 5: Potential Impact of Overcoming Barriers for the Thermochemical Platform

Barrier	Priority	Potential Cost Reduction (%)
Feed Processing & Handling	Low	5-10
Gasification & Pyrolysis	Medium	5-10
Cleanup & Conditioning		15-25
Sensors & Controls	Low	5-10
Syngas Utilization (Products)	High	10-15
Process Integration (Integrated Biorefineries)	High	5-10

Listed below is a brief description of each barrier area and, in each case, a list of specific needs within the area rated as high, medium or low. All areas are considered needed but with limited resources the ratings provide a consensus of the relative importance. In many cases the relative importance as indicated is more driven by what is needed first than by ultimate importance to the success of the demonstrations.

Feed processing and handling

Thermochemical platforms require a supply of uniform feedstock and reliable feed preparation, storage, and handling systems. Commercial operators must have quality control (QC) procedures to ensure uniformity in biomass feedstocks and for long-term fuel supply contracts. In addition, the history of biomass project development has taught that reliable feeders are key to any successful project or system. There are a number of feed systems that function reliably using feedstocks within a narrow range of physical properties (size, moisture, etc.). However with the potentially wide range of new feedstocks being considered for the bioeconomy have a wide diversity of properties. The task of adapting existing feed systems to handle the variety and complexity of biomass feedstock is a daunting task that has not yet been accomplished and is specific to individual feeds. An alternate approach is to develop in-plant feedstock handling that can economically convert a wide range of feedstocks to a consistent form that existing feeders need to function reliably. These approaches need to be balanced to arrive at the lost cost feed delivered to the thermal conversion device(s).

Table 6: Priorities for Addressing Feed Processing Issues for the Thermochemical Platform

Feed Processing	Priority (1=High)
Densification	2
Drying	1
Chemical modification	2
Feeders	1

Biomass and Black Liquor Gasification

Biomass and black liquor gasification are technologies that have developed to the point of large-scale demonstration. However, widespread commercial availability of gasifier systems suitable for integration with fuels synthesis or hydrogen separation technologies has not yet been realized. In part, this is due to areas of fuels chemistry that require additional investigation to support the commercial demonstration program and facilitate the development and scale-up of advanced gasifiers and gas clean-up systems.

A directed gasification chemistry technical support effort that provides usable results will maximize the chances of successful demonstrations. Gasification chemistry encompasses all chemical reactions, fluid dynamics, and phase equilibria behavior associated with the fuel, other reactants, transport gas, and gasification products. It also includes potential interactions with vessel refractories, reactor bed and heat transfer media.

It is generally agreed in the technical community that there is good understanding of global gasification and pyrolytic gasification chemistry. Historical development has concentrated on this area with less effort applied to understanding the fuel chemistry of minor products and residual solids. Better technical understanding of the formation and destruction of tars (condensable organic compounds heavier than benzene) and their ultimate impact on downstream unit operations will be required for commercial success. Tar destruction efforts may include both catalytic and non-catalytic methods.

The potential impact of gasification catalysts, both added catalysts and alkali compounds in the fuel, on tars and residual carbon needs to be understood. An understanding of residual carbon age distribution and composition is needed to optimize reactor design. The management of impurities such as sulfur,

halogens, nitrogen, and alkalis needs to be understood for process operability, for use of the product gas, and for environmental impact minimization. For complete understanding of how fuel chemistry affects commercial viability, reaction chemistry, fluid mechanics, and phase behavior should be incorporated into both rigorous and engineering computational fluid dynamic models for use in design and process control. Better understanding of fuel chemistry can also be applied to optimization of specific fuel throughput, e.g., kg/m²/s, to minimize capital cost. A prioritized list of fuel chemistry technical support areas is given Table 7.

Pyrolysis and Other Thermal Processing

Pyrolysis process development faces a number of challenges in producing oil with properties suitable for commercial usage. Instability of the oil, aging due to reactive components, phase separation, acidity, and environmental safety and health issues associated with long-term exposure need to be addressed. Since pyrolysis oil properties are significantly different than existing petroleum-based oils, new product specification and standards, e.g., ASTM standards, will need to be developed. This is a multi-year effort. To a large extent, these yet-to-be-determined standards will define additional technical developments for product cleanup, e.g., particulate and alkali removal. Demonstrations of oil for various end-use applications may be limited by lack of existing facilities to generate significant quantities of product for testing. A potential “show stopper” is the potential environmental impact associated with the safe transport of pyrolysis oil.

Table 7: Priorities for Addressing Fuel Chemistry Issues in the Thermochemical Platform

Thermal Processing	Priority (1=High)
Carbon Management	
Tars	
Tar Destruction	1
Tar Production	1
Catalytic Management	2
Non-catalytic Management	2
Gasification	
Catalysis	2
Alkali metals effects	2
Pyrolysis	2
Residual Carbon	2
Sulfur Management	1
Alkali Metals Management	1
Halogen Management	1
Nitrogen Management	2
Modeling	
Engineering	1
CFD	2
Specific Throughput	2

Technical challenges associated with hydrothermal treating of biomass include the normal issues associated with feeding and pressure let-down of high-pressure slurries, defining the properties of “bio-oils”, demonstrating the effectiveness of separation techniques, and demonstrating the commercial use of products. For wet gasification, a major challenge is demonstrating long-term catalyst effectiveness when using fixed-bed catalysts in the presence of inorganic particulates.

As discussed above, these processes are a relatively recent addition to the OBP Portfolio resulting from new EE/RE and Program priorities. In FY04, both their technical and economic benefits will be defined and a prioritized list of technical barriers developed similar to those for the gasification area.

Cleanup and conditioning

The raw gases from biomass gasification systems do not meet strict quality standards for downstream fuel or chemical synthesis catalysts nor those for some power technologies (fuel cells or fuel cell/turbine hybrids), and will require gas cleaning and conditioning to remove contaminants such as tar, particulates, alkali, ammonia, chlorine, and sulfur. Available cleanup technologies do not meet the needed cost, performance or environmental criteria needed to achieve the Program goals or commercial implementation. In the pyrolysis arena, research has shown that the stability and properties of pyrolysis oil are greatly enhanced if solids and inorganic contaminants can be rapidly removed after formation of the pyrolysis vapors and before condensation of the desired oil products. Significant progress has been made in this area; however addition development leading to a commercial process will be required if analysis indicates that this is a fruitful area for continued R&D. Similarly, treating and upgrading of pyrolysis oils will require novel approaches and this is discussed in the Products section of this document.

Priorities identified for cleanup and conditioning of biomass and black liquor gasification are reflected in Table 8.

Table 8: Priorities for Addressing Clean-up and Conditioning Barriers in the Thermochemical Platform

Cleanup and Conditioning	Priority (1=High)
Catalytic gas cleanup and conditioning	1
Catalyst fundamentals	2
Catalyst life time testing	1
Catalyst Deactivation	1
Catalyst Regeneration	2
Particulate removal	2
Novel hot gas filters	3
Fluid bed gasifier media attrition	2
Aerosol formation and growth	3
Non-condensing gas cleanup	2
<i>Residual carbon utilization</i>	
<i>Alkali control</i>	
Condensing gas cleanup water/organics separation Organics utilization Ammonia separation and use	2

Sensors and Controls

Effective process control will be needed to maintain plant performance and emissions at target levels with varying load, fuel properties, and atmospheric conditions. Development of new sensors and analytical instruments is needed to optimize control systems for thermochemical systems. Prioritized areas requiring sensor development appear in Table 9.

Table 9: Priorities for Addressing Sensors and Controls Barriers for the Thermochemical Platform

Sensors and Controls	Priority (1=High)
Feeding systems	3
Gasification systems	1
High Temperature Process Monitoring instrument	1
On-line tar sensor	2
On-line heteroatom monitoring <i>Sulfur</i> <i>Nitrogen</i> <i>Alkalies</i> <i>Halides</i>	2

Process Integration

As with all new process technologies demonstrating sustained integrated performance that meets technical, environmental, and safety requirements at sufficiently large scales is essential to supporting commercialization. Black liquor mill integration has the added complexity of being attached to an existing commercial process where the unit operations associated with steam production, power, pulping, and chemical recovery must all be integrated. Heat and process integration as well as being essential to all processes has additionally been identified by the OHFCIT as a critical technical barrier for economic hydrogen production.

Since most of these issues can only be addressed in the operation of a fully integrated process plant, this barrier is addressed in Section 5, Integrated Biorefineries in this plan. This includes both R&D that is specific to integration of bioenergy processes with existing biorefineries (e.g. causticization) and R&D required to provide increased efficiency to existing, emerging and advanced biorefineries (e.g. integrating biomass gasification with combined cycle heat and power production).

Containment (materials of construction)

Experience with the black liquor gasifier systems both in low-temperature but more particularly in high temperature reactors, clearly indicate that the reactions occurring in the gasification process are difficult to contain and that long term and economically acceptable approaches are yet to developed. Solutions to the containment issue are seen to involve metals used for reactor shells and in some cases internals, refractory materials used to line the containment vessels, the vessel design itself and significantly increased knowledge about bed behavior and agglomeration. Whereas the ideal solution may ultimately be materials that are unaffected by the fuel and reaction chemistry, innovative combinations of refractory, metals and innovative vessel design may be necessary to provide acceptable operating up-time and maintenance cost. Modeling and model verification of bed behavior is also seen as extremely important in enabling optimum reactor design and the prevention of catastrophic failure. All of these areas are believed to be of high importance as indicated in Table 10.

Table 10: Priorities for Addressing Containment Barriers for the Thermochemical Platform

Containment	Priority (1=High)
Metals	1
Refractories	1
Vessel Design	1
Bed Behavior/Agglomeration	1

The Role of Analysis

Technoeconomic analysis can be used to establish the relative impacts of these barriers (See Table 5). Published analyses suggest that the combined effect of addressing the four barriers shown below (Figure 2) represents a reduction of 44% in cost of the technology.

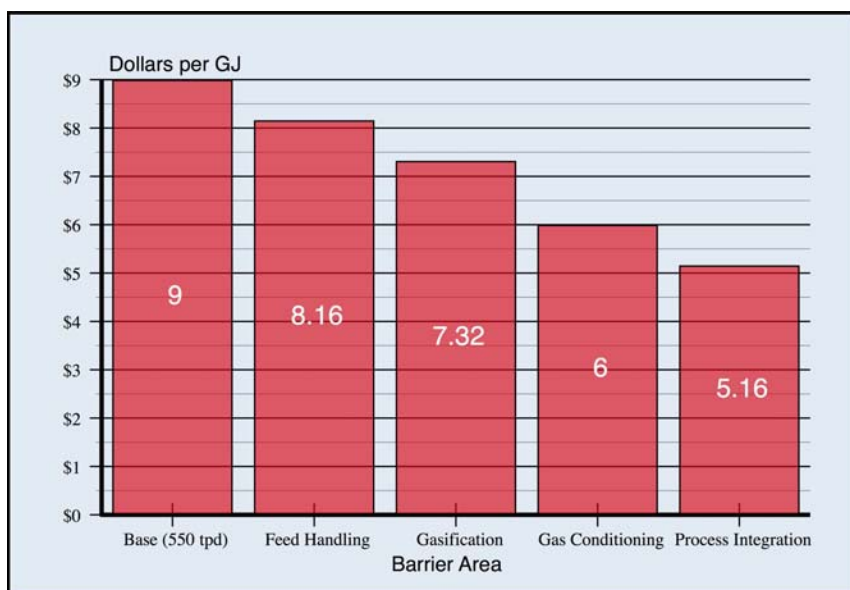


Figure 22: Translating Barrier Reductions to Cost Impacts for the Syngas Platform

Table 11 shows the potential impact of overcoming these barriers on the cost of products via the Thermochemical pathway. These costs assume the following contributions to product cost reduction in 2010: feed preparation/gasification - 10%; gas cleanup: 20%; system integration - 10%. The resulting costs are different from those that appear in the OHFCIT multi-year plan due to differences in economic assumptions and other factors, but clearly show that the OBP program goals will lead to the 2010 hydrogen cost goal.

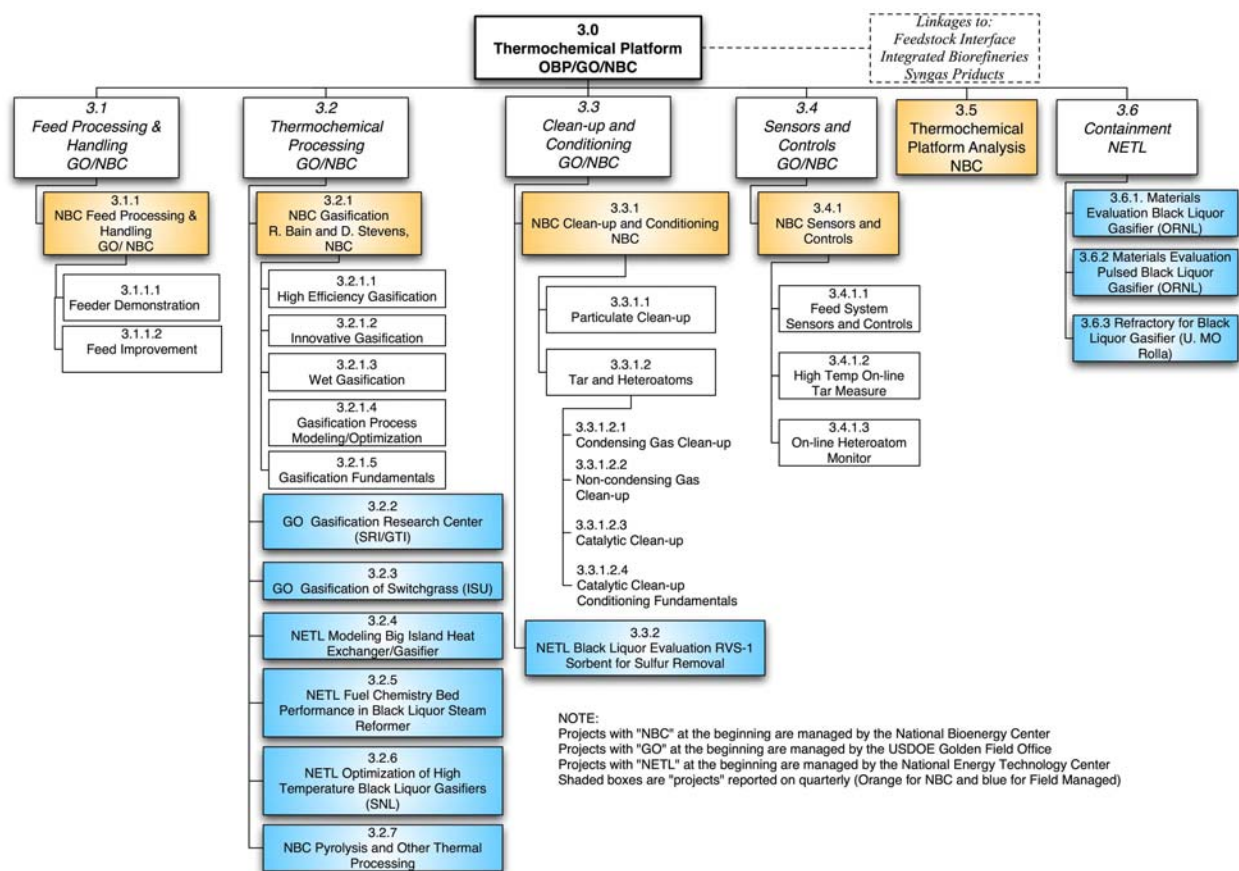
2.3.4 Technical Approach

To facilitate the development of advanced biomass gasification systems, OBP will conduct advanced R&D to address the technical barriers related to ensuring that the syngas product can be reliably produced and is compatible with requirements for converting it to fuels and chemicals. R&D activities will be conducted in the five areas

Table 11: Cost Reductions in Terms of Example Products

Year	2003	2005	2010	2015	2020	2025	2030
Min Syngas Selling Price (\$/GJ LHV)	9	8.3	6	5.6	5.1	4.7	4.3
Corresponding H ₂ Cost (\$/kg)	2.16	1.98	1.26	1.17	1.08	0.99	0.90
Product (e.g. methanol) (\$/gal)	1.30	1.20	0.90	0.70	0.65	0.60	0.54
Feedstock Cost (\$/dry ton delivered)	30	30	30	30	30	30	30
Plant Size (dry tons/day)	550	550	2,000	2,000	2,000	2,000	4,000

The technical approach for the Thermochemical Platform involves core research addressing the technical barriers to development and integrated industrial biorefinery demonstration projects addressing integration and system scale-up issues. The work breakdown structure for core research on the Thermochemical Platform is shown in Figure 23. A high level Gantt chart for all of the thermochemical platform-related work in the plan is shown in Figure 24.

**Figure 23: Work Breakdown Structure for the Thermochemical Platform Core R&D Area**

The work is organized in six areas corresponding to the five technical barriers plus one area devoted to analytical support. The latter includes technoeconomic and life cycle analysis used to quantify the benefits of research targets as well as to recommend targets for research. National Laboratories, industry, and universities will perform the core technical research. The industry and university projects will be selected through a targeted solicitation targeting specific technical issues. The majority of supporting core research will be completed by 2009. Note that this plan and approach includes the process elements and

schemes that are apparent today and does not include advanced process ideas or technology developments that may form the basis for new R&D areas in the future.

Industrial biorefinery (process integration) demonstration projects will be selected through competitive solicitations in the following areas: distributed fuels and chemicals systems, syngas production systems at existing petroleum and chemical and forest products facilities, and integrated biorefinery systems. These projects will form the core of moving enabling systems and technologies from the platform research area into commercial biorefinery as well as address the critical process integration (heat integration, waste minimization, etc.) issues that can only be examined in a truly integrated plant. Although these activities will be closely coupled to the platform research area, they will be managed as part of the Integrated Biorefinery activity (Section 2.5 of this document).

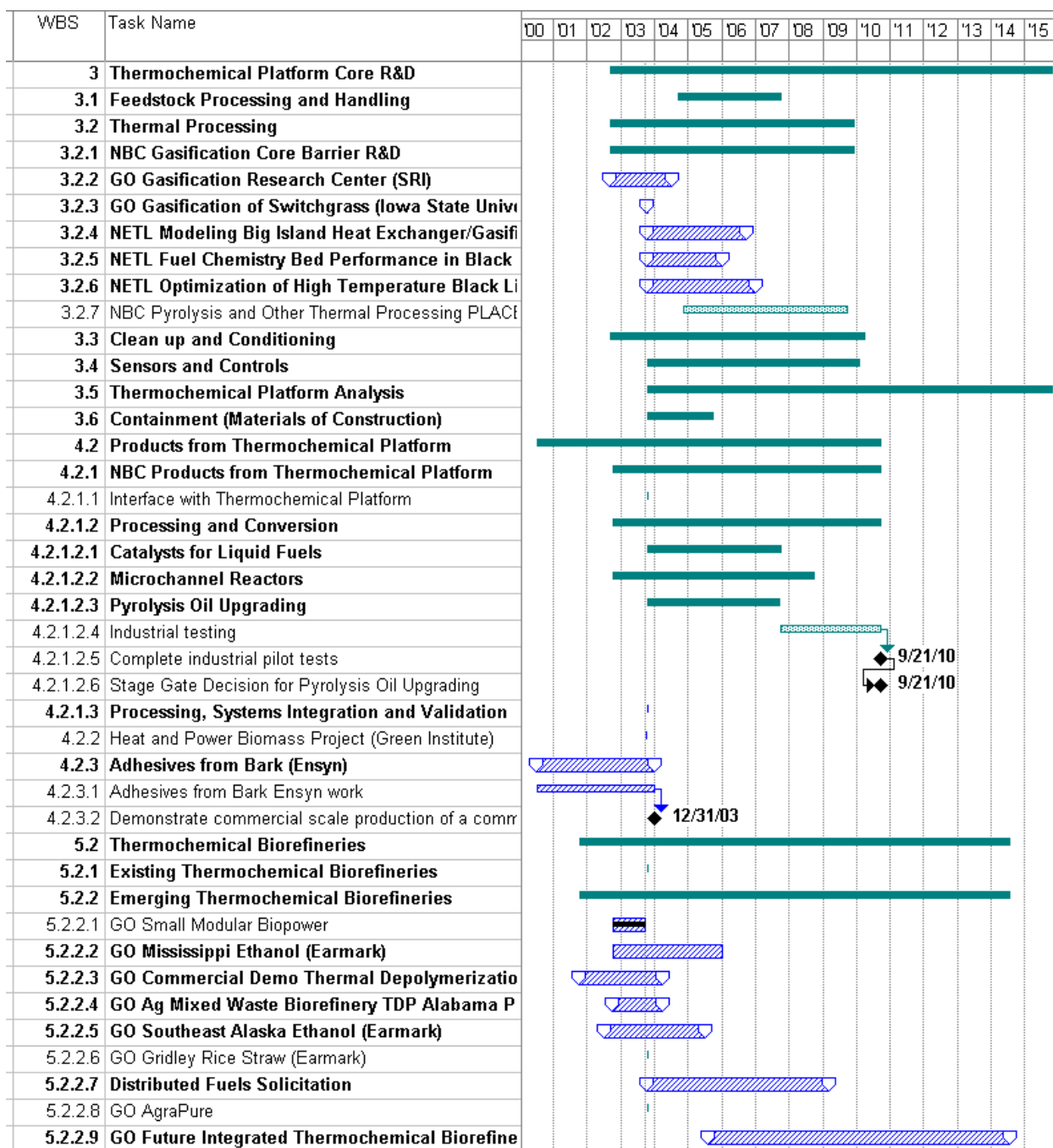


Figure 24: High Level Gantt Chart for All Thermochemical Platform-Related Activities

2.3.4.1 Feed process handling

OBP will conduct R&D activities to ensure that biomass feedstocks can be effectively supplied to biomass thermochemical conversion systems. A Gantt chart showing key activities for feed process handling is shown in Figure 25. Labs, universities, and industries will work to improve the integration of biomass feedstock harvesting and supply issues with in-biorefinery issues such as feedstock storage and drying requirements. The overall objective of this work will be to develop methodologies that allow biomass to be collected, prepared and gasified in a cost-effective manner. For biorefineries, it is important that the feedstock requirements of the conversion technology be met while also minimizing

preparation of the biomass material to reduce costs. This will require an optimization between the cost of plant-gate feedstock (and therefore coordination with the Feedstock area) with the handling and processing required to ensure reliable operation of the feeder. This optimization will have as a goal the minimum cost of feedstock as-fed to the conversion device (e.g. gasifier) With significant industry involvement, OBP will also conduct R&D to ensure that appropriate biomass feeder systems are available, particularly for pressurized gasification systems that have previously been shown to be critical technology barrier.

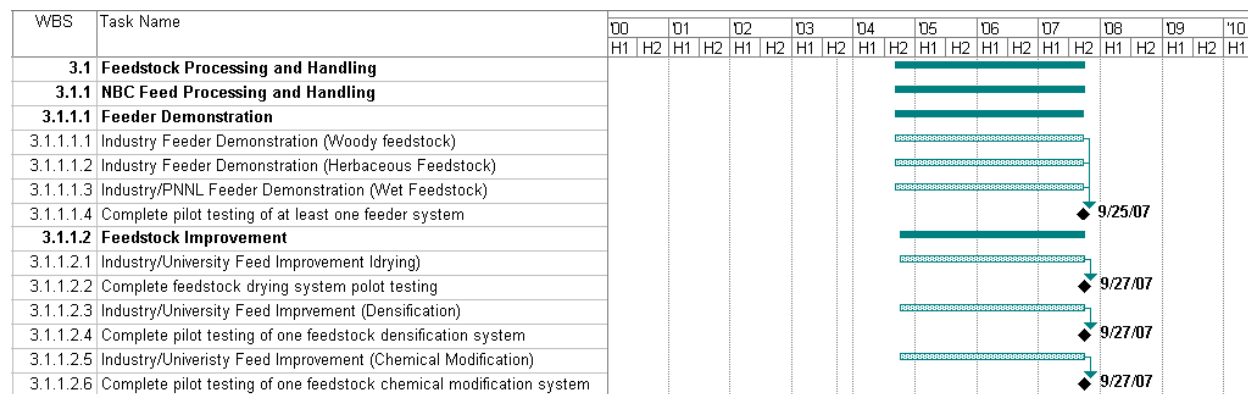


Figure 25: Biomass Program Activities Addressing the Feedstock Processing Barrier for the Thermochemical Platform

2.3.4.2 Thermal Processing

OBP will conduct R&D activities to ensure that appropriate biomass gasification technologies are available to convert a variety of biomass materials to syngas. The gasification step is the crucial first step in producing fuels and chemicals using this thermochemical conversion pathway. Figure 26 presents a Gantt chart of key activities in the plan related to the Gasification Core R&D area.

Working in partnership with industry, OBP will assist in resolving technical questions related to the operability and reliability of biomass and black-liquor gasification systems. OBP will conduct R&D necessary for integration of biomass gasifiers into biorefineries. The goal of this work will be to ensure that gasification technologies are shown to be technically feasible in longer-term applications that have the potential for ongoing economic feasibility. The focus will be on addressing key technology barriers and fundamental information needs (such as tar formation mechanisms, kinetics, or chemical recovery).

OBP will also conduct R&D on advanced gasification technologies to develop more efficient, cleaner gasification systems appropriate for a wide variety of biomass feedstocks. This work will include fundamental gasification studies, process modeling, and similar work to identify opportunities for technology improvements. Activities will also include R&D to identify and improve smaller-scale syngas systems for producing biofuels and biopower in distributed locations.

Partners in this work will include national labs, universities, and others. The OBP will build on the base of biomass gasification information developed over two decades by the previous Biomass Power Program, the Black Liquor Gasification Program, and other related activities. The Program will also evaluate other thermal processes (incl. pyrolysis) to determine their relative merit and impact on OBP goals as well as defining barrier areas and targets for success.

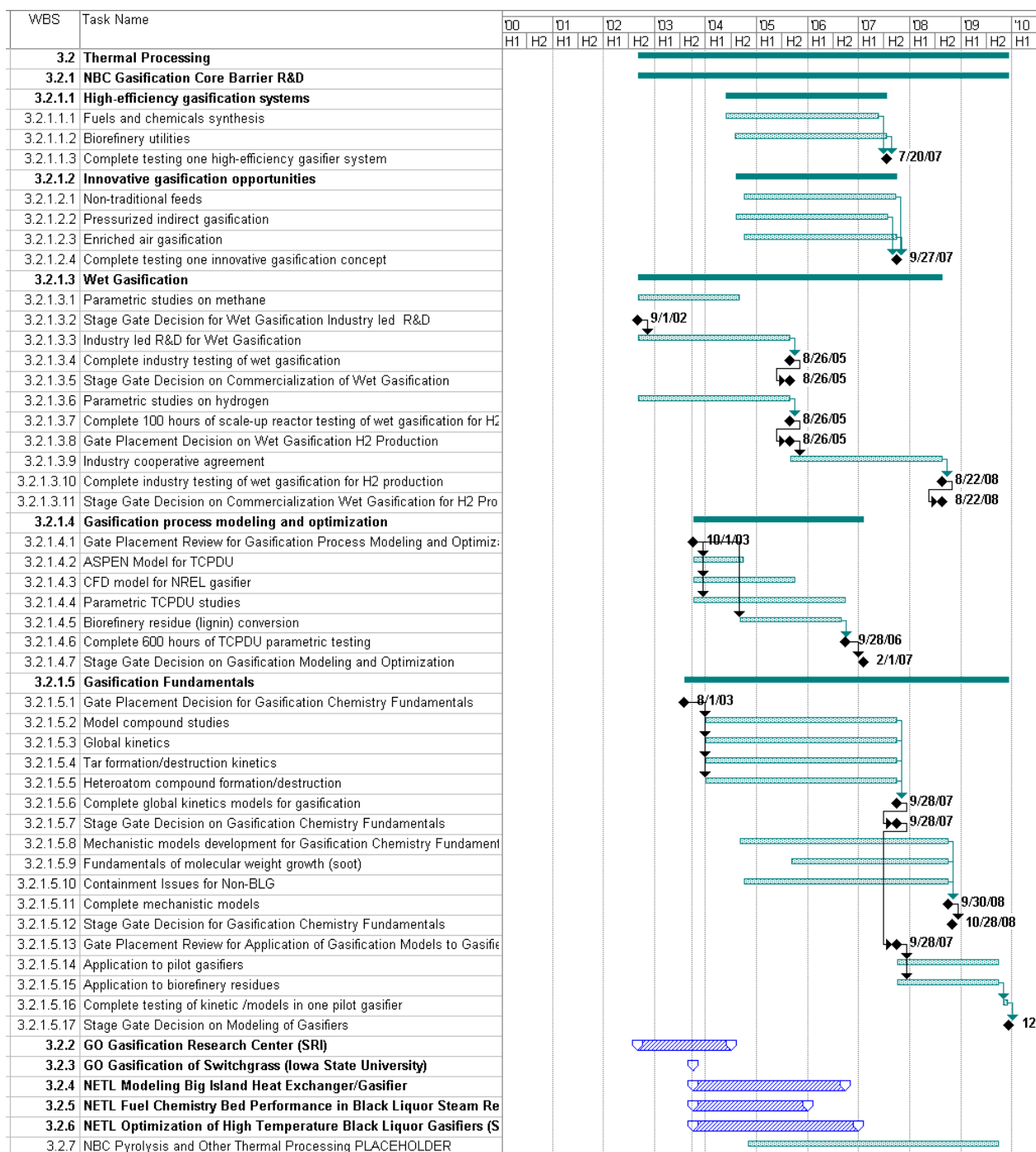


Figure 26: Biomass Program Activities Addressing the Barriers of Thermal Processing for the Thermochemical Platform

2.3.4.3 Cleanup and Conditioning

The recent expansion of this part of the program to include thermochemical processing in general means that we need to develop a scope and approach for other types of thermal processing. The bulk of the work included in this version of the MYTP for clean-up and conditioning is related to gasification technology.

Significant advances in syngas cleaning and conditioning are required for the raw gasification product to be used in downstream processes. Syngas cleaning involves removal of material such as tars or particulates from the gas stream, and conditioning involves further treatment of syngas to achieve a product containing mostly CO and H₂ that is suitable for synthesis to fuels and chemicals. Figure 27 lays out the key activities in the plan related to clean-up and conditioning of intermediates from thermal processing of biomass. OBP will partner with National Laboratories, universities, and industry to develop and evaluate advanced concepts in particulate removal and catalytic conversion of problematic syngas components. Activities will include:

- Analyzing hot gas particulate removal
- Examining the use of catalytic reforming for tar cracking
- Analyzing large-scale gas conditioning with catalysts
- Evaluating the chemistry and kinetics of biomass gasifier tar formation and removal
- Evaluation of advanced desulfurization adsorbents that remove reduced sulfur species from black liquor gasification products for re-use in the paper mill.

OBP will evaluate advanced concepts for particulate and tar removal in existing test-bed facilities and will explore options for new thermal and catalytic removal and treatment technologies and materials. Research is expected to improve gas cleaning and conditioning to allow biomass syngas to be effectively utilized for fuels and power production. Efforts will include work with biomass and biomass residues as well as black liquor. R&D in the area of improving capture of biomass pyrolysis liquids from gas stream will also be conducted.

2.3.4.4 Process control and optimization

OBP will conduct R&D to facilitate the development of sensors and controls necessary for syngas systems. A Gant chart of proposed activities for this area is shown in Figure 29. Better monitoring sensors are needed for biomass feed systems to ensure reliable feed supplies. Gasification of biomass also creates unique gas impurities such as heteroatom tars and alkali for which there is currently no adequate on-line sensors. OBP will partner with national labs, universities, and instrumentation developers to establish concepts for monitoring these and other gas-phase species during system operation. Development of such sensors and automated controlling systems is expected to improve the operability and reliability of biorefineries.

2.3.4.5 Thermochemical Platform Analysis

OBP will conduct analysis activities on the Thermochemical Platform to provide information to decision makers. (MYAP). Technoeconomic analyses will be performed to determine the costs of producing biofuels and chemicals using currently available technologies. The analyses will also evaluate major process steps and determine those areas where technical progress will be most successful in reducing project product costs. Life-cycle analysis will also be conducted to determine the sustainability of syngas pathways. Comparative analyses of the syngas pathways with those of other platforms will also be conducted to compare the relative advantages of each. This work will build upon expensive past efforts by the National Labs and universities in building various analysis tools. This analysis also supports OBP's goals and feeds into the Multi-Year Analysis Plan.

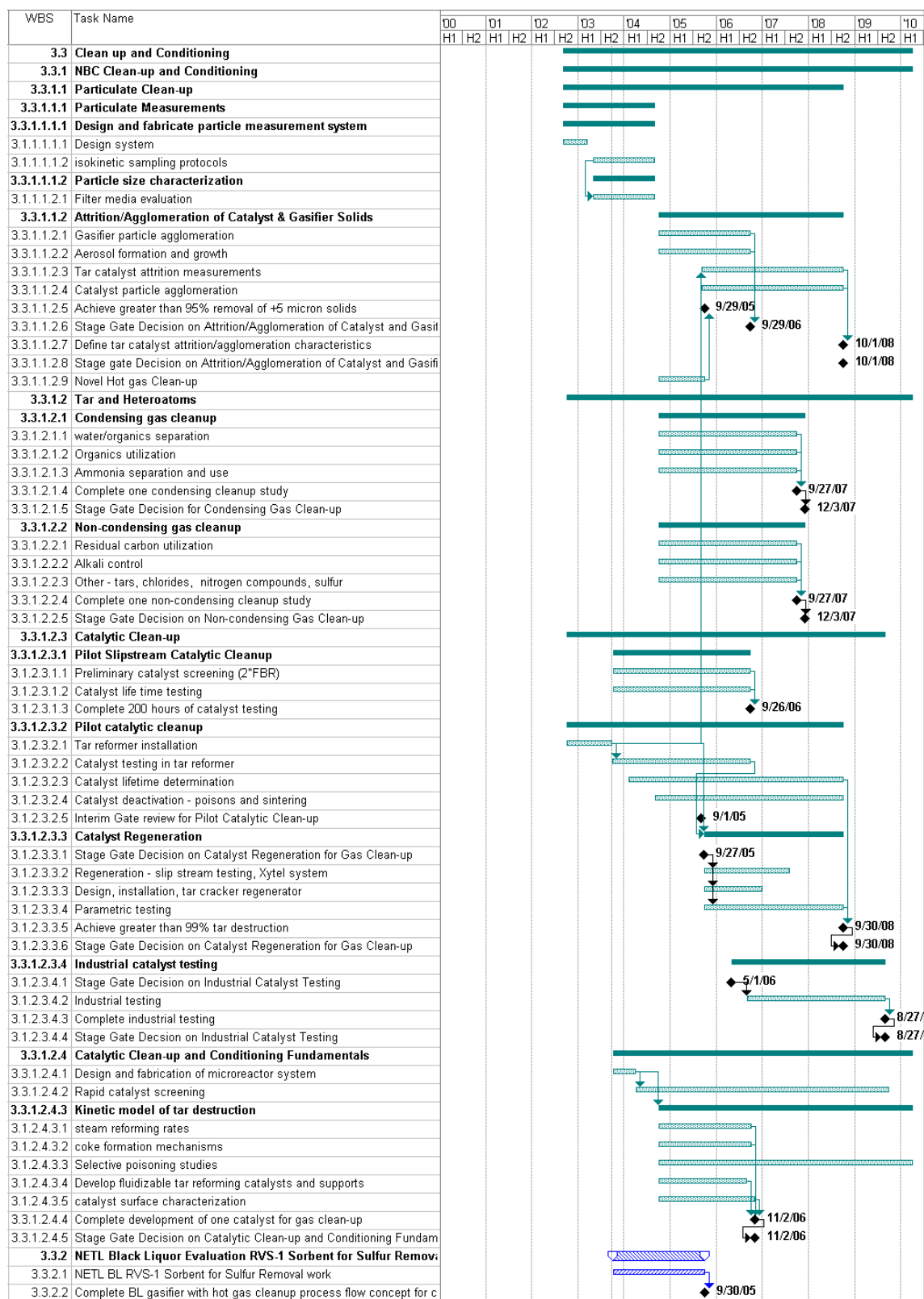


Figure 27: Biomass Program Activities Addressing the Barrier of Clean-up and Conditioning for the Thermochemical Platform

2.3.5 Resource Allocation Plan

Figure 28 and Table 12 summarize the resource allocation plan for the Thermochemical Platform Core R&D area.

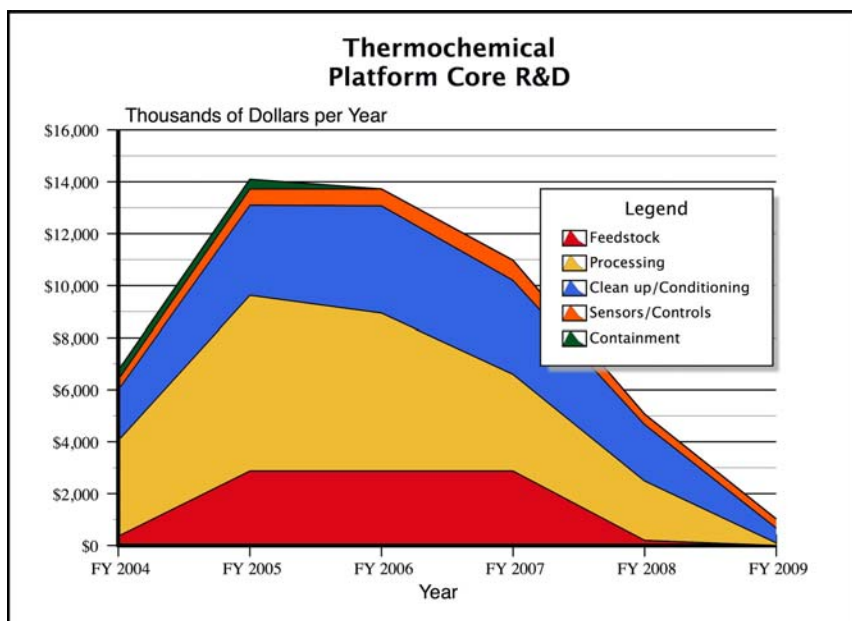


Figure 28: Thermochemical Core R&D Resource Plan

2.3.6 Thermochemical Platform Projects and Milestones

Table 13 summarizes all of the projects included in the thermochemical platform, organized according to major barrier areas for the platform. Information is also included on the specific barriers addressed by each project and their milestones.

Table 12: Thermochemical Platform Core R&D Resource Plan

WBS	Title	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09
3	Thermochemical Platform Core R&D	\$1,697	\$7,207	\$17,172	\$14,375	\$11,850	\$6,545	\$2,925
3.1	Feedstock Processing and Handling		\$400	\$2,875	\$2,875	\$2,875	\$200	\$-
3.1.1	NBC Feed Processing and Handling		\$400	\$2,875	\$2,875	\$2,875	\$200	\$-
3.1.1.1	Feeder Demonstration		\$150	\$1,375	\$1,375	\$1,375	\$50	
3.1.1.2	Feedstock Improvement	\$-	\$250	\$1,500	\$1,500	\$1,500	\$150	\$-
3.2	<i>Thermal Processing</i>	<i>\$1,697</i>	<i>\$3,797</i>	<i>\$7,345</i>	<i>\$6,070</i>	<i>\$3,725</i>	<i>\$2,290</i>	<i>\$100</i>
3.2.1	<i>NBC Gasification Core Barrier R&D</i>		<i>\$1,400</i>	<i>\$6,155</i>	<i>\$6,070</i>	<i>\$3,725</i>	<i>\$2,290</i>	<i>\$100</i>
3.2.1.1	High-efficiency gasification systems		\$100	\$1,000	\$1,000	\$50		
3.2.1.2	Innovative gasification opportunities		\$150	\$1,500	\$1,500	\$50		
3.2.1.3	Wet Gasification		\$500	\$2,000	\$2,050	\$1,000	\$550	
3.2.1.4	Gasification process modeling and optimization		\$400	\$860	\$625	\$700	\$50	
3.2.1.5	Gasification Fundamentals		\$250	\$795	\$895	\$1,925	\$1,690	\$100
3.2.2	GO Gasification Research Center (SRI)	\$1,697	\$1,697					
3.2.3	GO Gasification of Switchgrass (Iowa State University)							
3.2.4	NETL Modeling Big Island Heat Exchanger/Gasifier		0	\$500				
3.2.5	NETL Fuel Chemistry Bed Performance in Black Liquor Steam Reformer		\$0	\$90				
3.2.6	NETL Optimization of High Temperature Black Liquor Gasifiers (SNL) funding dependant FY04-5 appropriations		\$700	\$600				
3.2.7	NBC Pyrolysis and Other Thermal Processing PLACEHOLDER							
3.3	<i>Clean up and Conditioning</i>		<i>\$1,830</i>	<i>\$4,120</i>	<i>\$3,680</i>	<i>\$3,375</i>	<i>\$2,555</i>	<i>\$1,375</i>

WBS	Title	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09
3.3.1	<i>NBC Clean-up and Conditioning</i>		\$1,830	\$3,530	\$3,680	\$3,375	\$2,555	\$1,375
3.3.1.1	Particulate Clean-up		\$430	\$430	\$230			
3.3.1.2	<i>Tar and Heteroatoms</i>		\$1,400	\$3,100	\$3,450	\$2,625	\$2,555	1,375
3.3.1.2.1	Condensing gas cleanup		\$150	\$750	\$750	\$750	\$50	
3.3.1.2.2	Non-condensing gas cleanup		\$150	\$750	\$750	\$750	\$50	
3.3.1.2.3	Catalytic Clean-up		\$750	\$1,050	\$1,350	\$1,625	\$1,975	\$800
3.3.1.2.4	Catalytic Clean-up and Conditioning Fundamentals		\$350	\$550	\$600	\$500	\$475	\$575
3.3.2	NETL Black Liquor Evaluation RVS-1 Sorbent for Sulfur Removal		\$0	\$590				
3.4	<i>Sensors and Controls</i>		\$400	\$625	\$650	\$775	\$400	\$350
3.4.1	<i>NBC Sensors and Controls</i>		\$400	\$625	\$650	\$775	\$400	\$350
3.4.1.1	Feeding System Sensors and Controls		\$50	\$250	\$250	\$175		
3.4.1.2	High Temperature On-line Tar Measure		\$350	\$375	\$400	\$600	\$400	\$350
3.4.1.3	On-line Heteroatom Monitor							
3.5	Thermochemical Platform Analysis		\$780	\$1,200	\$1,100	\$1,100	\$1,100	\$1,100
3.6	<i>Containment (Materials of Construction)</i>		\$0	\$1,007				
3.6.1	Materials Evaluation Black Liquor Gasifier (ORNL)		\$0	\$778				
3.6.2	Materials Evaluation Pulsed Black Liquor Gasifier (ORNL)		\$0	\$229				
3.6.3	Refractory for Black Liquor Gasifier (U.MO Rolla)		\$0	\$0				

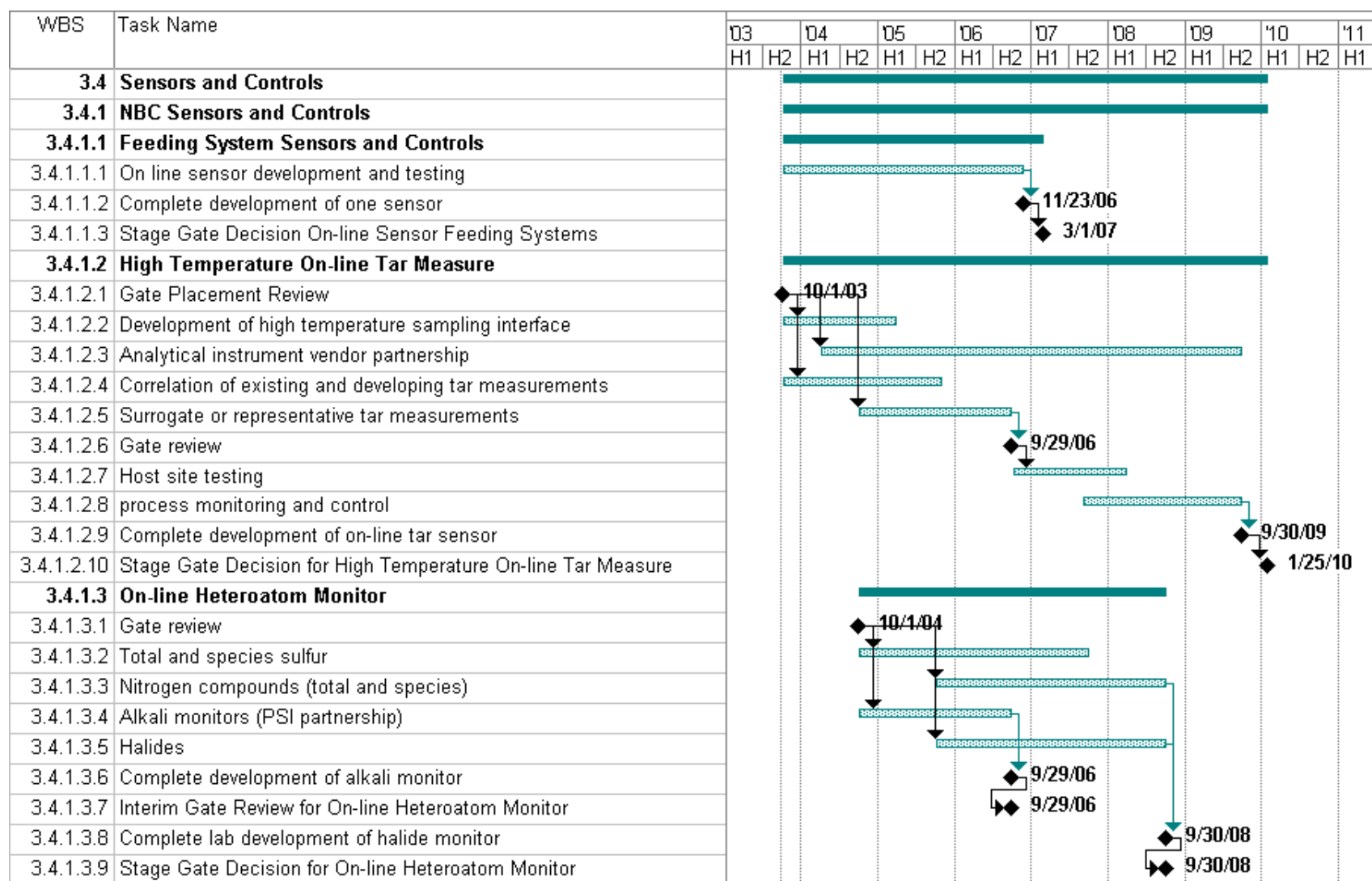


Figure 29: Biomass Program Activities Addressing the Sensors and Controls Barrier for the Thermochemical Platform

Table 13: Thermochemical Platform Core R&D Projects and Milestones

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
NBC Feed Processing & Handling NOTE: Proposed topics for FY04 focused R&D solicitation	3.1.1.1 Feeder Demonstration	<ul style="list-style-type: none"> Supply a uniform feedstock. (MYTP) Reliable feed preparation. (MYTP) Storage and handling. (MYTP) Improved feeders for high and low-pressure gasifiers (MYTP task description) 	12/2003: Define desired characteristics of commercial feeders. 09/2004: Feeder development solicitation, FY04 10/2007: Complete pilot testing of at least one feeder that meets defined specifications.
	3.1.1.2 Feedstock improvement – Drying, Densification, Chemical Modification	<ul style="list-style-type: none"> Supply a uniform feedstock. (MYTP) Reliable feed preparation. (MYTP) Storage and handling. (MYTP) Lack of efficient, safe dryers (MYTP task description) 	12/2003: Define desired characteristics of thermochem feedstocks based on optimized pre- and in-plant handling costs 09/2004: Feed improvement solicitation 10/2007: Complete testing of feed improvement system that meets the defined criteria.
Thermochemical Processing GO/NBC	3.2.1 NBC Gasification		
	3.2.1.1 High efficiency gasification (O ₂ or enriched air) NOTE: Proposed topic for FY04 focused R&D solicitation	<ul style="list-style-type: none"> Lack of demonstrated, reliable gasifiers suitable for integration with fuel synthesis or hydrogen production (MYTP) 	09/2004: High efficiency gasification solicitation 10/2007: Complete development of one gasifier suitable for hydrogen, fuels, or chemical production
	3.2.1.2 Innovative gasification opportunities	<ul style="list-style-type: none"> Perceived need for small syngas to synfuels catalytic conversion processes for distributed refineries. (MYPP) 	09/2004: Solicitation for feasibility studies of distributed biorefineries 09/2005: Evaluate results of feasibility studies and issue development solicitation if indicated.

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	3.2.1.3 Wet gasification	<ul style="list-style-type: none"> Lack of an effective method to convert wet residues to energy-related products (inferred from MYTP task objective) 	09/2004: Complete updated economic analysis and assessment of additional feedstocks 09/2004: Complete 100 hrs of scaled-up reactor testing on methane 10/2007: Complete industry testing for methane generation 09/2008: Complete industry testing for hydrogen
	3.2.1.4 Gasification process modeling and optimization	<ul style="list-style-type: none"> Insufficient understanding of fuels chemistry for commercialization and process scale-up and optimization (inferred from MYTP barrier description) 	10/2006: Identify process variables and conditions that minimize formation of undesired impurities 10/2008: Integrate tar kinetics models in process models
	3.2.1.5 Gasification fundamentals	<ul style="list-style-type: none"> Insufficient/inadequate CFD modeling tools to support commercialization (inferred from MYTP task description) 	10/2005: Complete evaluation of one tar kinetics model and potential for effecting reduced tar formation 10/2007: Complete comprehensive tar kinetics models 10/2008: Mechanistic models development for heteroatom-containing compound conversions
	3.2.2 GO Gasification Research Center (SRI/GTI)	<ul style="list-style-type: none"> Understanding gas clean-up for removal of tars, particulate, alkali, ammonia, chlorine and sulfur. (MYTP) Unproven gas cleanup and conditioning technologies and systems. (MYPP) Removal of sub-micron particles and effect of process conditions on particulate size/capture not well understood (inferred from MYTP task description) 	12/2003 Complete Facility Design with $\pm 10\%$ cost estimate (SRI) 4/2004 Complete Slipstream Design (GTI) 1/2004 Develop comprehensive Test Plan (GTI) 7/2004 Procurement and Construction (GTI) 12/2004 Installation, Checkout, and Shakedown Testing (GTI) 4/2005 Complete Test Period One (GTI)

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	3.2.3 GO Gasification of switchgrass (ISU)	<ul style="list-style-type: none"> Understanding gas clean-up for removal of tars, particulate, alkali, ammonia, chlorine and sulfur. (MYTP) Unproven gas cleanup and conditioning technologies and systems. (MYPP) Removal of sub-micron particles and effect of process conditions on particulate size/capture not well understood (inferred from MYTP task description) Lack of demonstrated, reliable gasifiers suitable for integration with fuel synthesis or hydrogen production (MYTP) 	<p>?/200?: Improve the overall cold-gas efficiency of the gasifier</p> <p>?/200?: Establish methodology for reliable hydrogen chloride (HCl) measurements;</p> <p>?/200?: Demonstrate a combined particulate matter/trace contaminant control system</p> <p>?/200?: Evaluate the feasibility of a combined catalytic reaction/carbon dioxide sorbent system;</p> <p>?/200?: Perform economic assessment of ballasted gasifier system</p>
	3.2.4 NETL Modeling Big Island Heat Exchanger/Gasifier	<ul style="list-style-type: none"> Insufficient/inadequate CFD modeling tools to support commercialization (MYTP) 	<p>12/2003: Complete 2-D and 3-D CFD hydrodynamics models of G-P BL gasifier</p> <p>09/2004: Complete 3-D CFD model with chemistry for G-P BL gasifier</p> <p>9/2006: Validate CFD models of G-P BL gasifier</p>
	3.2.5 NETL Fuel Chemistry Bed Performance in Black Liquor Steam Reformer	<ul style="list-style-type: none"> Insufficient understanding of fuels chemistry for commercialization and process scale-up and optimization (MYTP) Insufficient/inadequate CFD modeling tools to support commercialization (MYTP) 	<p>09/2004: Using lab-scale reactor, identify process variables & conditions that optimize gasification in low-temperature reformer</p> <p>09/2005: Identify process variables & conditions that optimize gasification in high-temperature reformer</p> <p>12/2005: Integrate optimization controls into commercial process models</p> <p>06/2005: Complete 2-D and 3-D CFD hydrodynamics models of low-and high-temperature gasifier</p> <p>12/2005: Validate CFD models of low-and high-temperature gasifier</p>

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	3.2.6 NETL Optimization of High Temperature Black Liquor Gasifiers (SNL)	<ul style="list-style-type: none"> Insufficient understanding of fuels chemistry for commercialization and process scale-up and optimization (inferred from MYTP barrier description) Insufficient/inadequate CFD modeling tools to support commercialization (inferred from MYTP task description) 	<p>Note: Project is on hold pending FY'04 appropriations</p> <p>09/2004: Complete design on high-pressure, high-temperature gasifier lab-scale unit.</p> <p>09/2005: Identify mechanisms for black liquor drying & oxidation</p> <p>12/2005: Identify soot & tar formation mechanisms</p> <p>06/2006: Develop spray droplet formation and transport & radiative properties database</p> <p>12/2006: Generate extensive database of algorithms and comprehensive CFD model calculations that demonstrates prediction of commercial scale gasifier operation & performance over a range of practical conditions</p>
	3.2.7 NBC Pyrolysis and Other Thermal Processing		
NBC Cleanup and Conditioning GO/NBC	3.3.1 NBC Cleanup and Conditioning		
	3.3.1.1.1 Particulate measurements	<ul style="list-style-type: none"> Understanding gas clean-up for removal of tars, particulate, alkali, ammonia, chlorine and sulfur. (MYTP) Unproven gas cleanup and conditioning technologies and systems. (MYPP) Removal of sub-micron particles and effect of process conditions on particulate size/capture not well understood (inferred from MYTP task description) 	10/2005: Demonstrate technology to achieve greater than 95% removal of < 5-micron solids for biorefinery applications

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	3.3.1.2 Tar and Heteroatoms	<ul style="list-style-type: none"> Understanding gas clean-up for removal of tars, particulate, alkali, ammonia, chlorine and sulfur. (MYTP) Unproven gas cleanup and conditioning technologies and systems. (MYPP) 	
	3.3.1.2.1 Condensing gas cleanup NOTE: Proposed topic for FY04 focused R&D solicitation	<ul style="list-style-type: none"> Removal of ammonia and chlorides and foaming issues in the presence of tars (MYTP) 	09/2004: Condensing gas cleanup solicitation, FY04 10/2007: Complete one condensing gas cleanup study
	3.3.1.2.2 Non-condensing gas cleanup for high pressure gasifiers NOTE: Proposed topic for FY04 focused R&D solicitation	<ul style="list-style-type: none"> Lack of suitable high temperature filter materials (physical strength and chemical attach issues) (MYTP) 	09/2004: Non-condensing gas cleanup solicitation, FY04 10/2007: Complete one non-condensing gas cleanup study
	3.3.1.2.3 Catalytic Cleanup	<ul style="list-style-type: none"> Understanding gas clean-up for removal of tars, particulate, alkali, ammonia, chlorine and sulfur. (MYTP) Unproven gas cleanup and conditioning technologies and systems. (MYPP) Lack of suitable tar cracking catalysts (inferred from MYTP task description) 	12/2003: Tar reformer installation 10/2005: Develop a fluidizable tar reforming catalyst for scaled-up testing 01/2006: Complete lifetime testing to identify catalyst for use in full-stream reformer 10/2008: Achieve greater than 99% tar destruction with regenerated catalyst 09/2008: Complete industrial verification of catalyst

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	3.3.1.2.4 Catalytic Clean-up Conditioning Fundamentals	<ul style="list-style-type: none"> Understanding gas clean-up for removal of tars, particulate, alkali, ammonia, chlorine and sulfur. (MYTP) 	06/2004: Design and fabrication of microreactor system 09/2008: Selective poisoning studies 09/2006: Develop fluidizable tar reforming catalysts and supports 09/2006: Catalyst surface characterization
	3.3.2 NETL Black Liquor Evaluation RVS-1 Sorbent for Sulfur Removal	<ul style="list-style-type: none"> Understanding gas clean-up for removal of tars, particulate, alkali, ammonia, chlorine and sulfur. (MYTP) 	12/2004: Demonstrate at lab-scale the NETL sorbent to removal sulfur from syngas produced in black liquor gasifiers 09/2005: Complete BL gasifier with hot gas cleanup process flow concept for commercial integration into paper mill
Sensors and Controls	3.4.1 NBC Sensors and Controls		
	3.4.1.1 Feed system sensors and controls NOTE: Proposed subject for FY04 focused R&D solicitation	<ul style="list-style-type: none"> Inadequate control systems technology for gasifier systems and subsystems. (MYPP) Process control for performance and emissions, fuel properties, atmospheric conditions, (MYTP). Process technology demonstrating sustained integrated performance that meets environmental and safety requirements. (MYTP) Lack of real-time feed sensor for moisture and composition (from MYTP task description) 	09/2004: Feed sensor solicitation, 10/2006: Complete development of real-time feed sensor
	3.4.1.2 High temperature on-line tar measurement	<ul style="list-style-type: none"> Inadequate control systems technology for gasifier systems and subsystems. (MYPP) Process control for performance and emissions, fuel properties, atmospheric conditions, (MYTP). 	10/2006: Complete development of on-line alkali monitor 10/2009: Complete development of on-line tar monitoring instrument

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	3.4.1.3 On-line heteroatom monitor	<ul style="list-style-type: none"> Inadequate control systems technology for gasifier systems and subsystems. (MYPP) Process control for performance and emissions, fuel properties, atmospheric conditions, (MYTP). 	<p>10/2006: Complete development of on-line alkali monitor</p> <p>10/2009: Complete development of on-line tar monitoring instrument</p>
Syngas Platform Analysis	3.5 Syngas platform analysis	<ul style="list-style-type: none"> Provide direction and focus to R&D by evaluating the technical, economic and environmental aspects of biomass syngas production and conversion. 	<p>07/2004: Complete review of merchant syngas market</p> <p>01/2005: Complete multi-lab biomass to H2 LCA study</p> <p>05/2004: Complete ASPEN modeling of pyrolysis system</p> <p>09/2004: Design study for thermochemical biorefinery</p>
Containment NETL (MYPP, not in MYTP)	3.6.1 Materials evaluation for black liquor gasifier (ORNL)	<ul style="list-style-type: none"> Reliability and cost of materials for vessels and refractories. (MYPP) Metals used for shells and internals (MYTP) Refractory materials to line containment vessels. (MYTP) 	<p>12/2003: Complete simulated lab-scale tests of chemical, thermal and mechanical cycling environments of gasifiers</p> <p>12/2003: Install metallic and refractory samples in fluidized-bed BL gasifier at Georgia-Pacific mill</p> <p>09/2005: Characterize exposure samples of metallic and refractory materials.</p>
	3.6.2 Materials evaluation for Pulsed black liquor gasifier (ORNL)	<ul style="list-style-type: none"> Reliability and cost of materials for vessels and refractories. (MYPP) Metals used for shells and internals (MYTP) Refractory materials to line containment vessels. (MYTP) 	<p>12/2003: Complete design of 12-tube bundle PDU of Pulsed-Enhanced steam reformer</p> <p>09/2004: Complete intermediate-duration tests of metallic and refractory samples in PDU</p> <p>09/2005: Complete long-term tests of metallic and refractory samples in PDU</p>
	3.6.3 Select/develop refractory for black liquor gasifier (University of Missouri – Rolla)	<ul style="list-style-type: none"> Reliability and cost of materials for vessels and refractories. (MYPP) Refractory materials to line containment vessels. (MYTP) 	<p>09/2003: Select suitable refractory materials to meet criteria in BL gasifier environments.</p> <p>09/2004: Investigate refractories with acceptable smelt infiltration and corrosion resistance at elevated temperatures.</p> <p>09/2005: Submit satisfactory materials for industrial trial.</p>

2.4 Products

The multiyear program plan (MYPP) for the OBP describes work conducted under broad heading of the Utilization of Platform Outputs (UPO) or Products R&D including the specific products depicted in Table 14

Table 14: Classes of Products R&D

Biobased Fuels for Transportation Markets:
Ethanol, alcohol blends, Fischer-Tropsch liquids, biooils, biodiesel (methyl and ethyl esters), fuel additives, oxygenates and hydrogen.
Biobased Products for Chemicals and Materials Markets:
Drop-in replacements for existing commodity chemicals.
New commodity chemicals for existing or new applications (improved performance, new functions, etc.).
Building blocks for production of a variety of secondary chemicals.
Electricity and Heat for Utility Markets
From distributed systems using biomass or as part of a grid connected biorefinery.

For OBP to make a significant contribution to EERE's strategic goals all three classes of products (biobased fuels, biobased products, and biopower) must be included in the Products R&D portfolio. Producing biobased fuels will allow OBP to have a significant impact on reducing dependence on foreign oil. Producing biobased products will help create the new, domestic bioindustry and reduce dependence on foreign oil. Production of process heat and power is required to eliminate biorefinery residues, improve the efficiencies of the biorefineries, and encourage biomass usage.

Similar to a petrochemical refinery all three of the classes of products will be produced by the biorefinery. The relative amount of these three classes of products and the specific products within a class will vary widely. One of the main factors that will impact the specific suite of products coming from a specific biorefinery is the source and composition of the biomass feedstock.

In addition to production of a suite of products the biorefinery is analogous to a petroleum refinery in a second facet. This second facet is the need for complete utilization of all the biomass feedstock, minimization of all emissions, and careful integration of the heat and power requirements. The Products R&D efforts are responsible for, wherever possible, identifying value-added products from all components of the biomass feedstock, while considering integration for reducing emission, and production of heat and power.

Biomass components coming from the sugars platform, the thermochemical platform and other biomass sources will vary widely depending on the source of the biomass and the processes used to isolate different components. Different biomass components are produced from different processes as shown in Table 2. This table highlights the wide variety of biomass component streams coming out of the sugars platform. The number of biomass component streams coming from the thermochemical platform is smaller than for the sugars platform, but within each component stream the chemical differences resulting from different processing conditions (primarily time and temperature) are great. There are also a number of other biomass components, mainly polymeric sugars, lignin and extractives, and oils and fats that can be obtained directly from biomass outside or within a platform type. Many of the polymeric sugars and extractives already have large volume, value-added markets, and reducing their costs would enhance their utilization.

Table 15: Common Biomass Components Produced by the Platforms and from other Sources

Biomass Components from the Sugars Platform	Biomass Components from the Thermochemical Platform
Six Carbon Sugars Five Carbon Sugars Lignin/Ash Extractives Protein	Permanent gases (CO, CO ₂ , H ₂ , H ₂ O, CH ₄ , etc) Condensable biooil liquids Char/Ash
Other biomass components that can be isolated from biomass include cellulose, starch, hemicelluloses, lignin, extractives, crop oils, protein, animal fats	

As described in the MYPP, the Products R&D work has a significant near-term focus on the sugars and thermochemical platforms. But it also includes additional work on oil-based products, technoeconomic and lifecycle analyses, and congressionally mandated projects

2.4.1 Technical Goals and Objectives

All R&D in the Products area focused on allowing OBP to meet EERE's goals of reducing dependence on foreign oil and helping to create the new, domestic bioindustry.

To meet the goal of significantly reducing dependence on foreign oil the Products R&D includes work on the processing and conversion of the biomass components, e.g., sugars and lignin, thermochemical outputs, to liquid fuels and petroleum replacements. The R&D activities for production of liquid fuels include advanced fermentation for production of ethanol, catalysts for clean-up and conversion of syngas, biooil upgrading, and improved processing of biodiesel. All of these products will play a significant role in reducing dependence on foreign oil.

In addition Products R&D supports the creation of the new, domestic bioindustry by establishing the viability of four commodity scale chemicals or materials co-produced in an integrated biorefinery by 2010. Interim goals include demonstrations of two of these biobased products by 2005. The development of specific chemicals and materials for specific markets will require industrial partners with a very clear understanding of the performance attributes and dynamics of the market.

In addition, it is expected that the production of biobased products can contribute to the technical targets of the sugar and syngas platforms - \$0.07/lb sugars from lignocellulosics and \$6/MMbtu syngas, respectively.

To accomplish these goals OBP will pursue two strategic pathways. The first pathway (Strategy one) includes the majority of the Products R&D work is focused on R, D & D efforts that are cost-shared with industrial partners who are capable of defining the cost advantages and performance characteristics of biobased products, and who have a clear understanding of the competitive market-place. The second pathway (Strategy two) will includes a component of precompetitive R&D activities that are focused on increasing knowledge and overcoming fundamental barriers in areas such as improved fermentations, catalysis and separations, and insuring complete utilization of all the feedstock components and minimization of emissions.

2.4.2 Programmatic Status

Activities included in the Products R&D portfolio include a very broad array of technologies. In part, this is because prior to creation of OBP three different EERE Programs conducted work in “products”. The Biofuels Program focused on production of ethanol and biodiesel fuels. The Biomass Power program focused on production of heat and power, and to a much lesser extent gasification for power and chemical products. Production of value-added bioproducts was the focus of the Agriculture Industries of the Future within the Office of Industrial Technologies. Now the products activities from all three programs have been merged into the Products R&D activities described here.

Due to this legacy the work currently being conducted in Products R&D is not completely balanced in terms of the emphasis on fuels or chemicals and materials, or between sugars, thermochemical, oils or the other biomass components used as feedstocks. There are no projects focused on utilization of a number of biomass components, e.g., lignin, char, extractives and protein residues from ethanol production.

- *Products from Sugars Platform*

There are two projects (Arabinose Yeast CRADA, Ethanologen Research) focused on improving the conversion of five carbon or mixed sugar streams to ethanol. There are three additional projects (Chemical Catalysis, Bioseparative Reactor, Development of Yeasts for Production of Chemicals) focused on developing improved processes for the conversion and separation of value-added products. Finally, there is one project (Acid Catalyzed Hydrolysis) focused on conversion of biomass waste streams to hydrogen.

- *Products from the Thermochemical Platform*

There are two projects (Catalysts for Liquid Fuels, Microchannel Reactors) focused on developing technology for production of liquid fuels for syngas. There are two more projects (Adhesives from Wood Bark, Pyrolysis Oil Upgrading) that are focused on production of value-added chemical from condensed biooils. Finally, there are two projects (Biorefineries Utilities, Heat and Power Biomass Project) focused on integration of the heat and power into the both the sugars and thermochemical platforms.

- *Products from Oils*

There is one project (Renewable Diesel Technology), with several components, focused on increasing production of biodiesel from oilseeds and animal fats. There are three projects (Chemicals from Oilseeds, National Ag-based Lubricants Center, Polymer Building Blocks from Vegetable Oils) that are focused on production of value added chemicals and materials from oilseeds.

- *Enabling Products*

There are three projects (Biorefinery for Polymers and Fuels, Genomics for Enhanced Bio-Products from Sorghum, Energy from Biomass Research and Technology Transfer) focused of developing novel technology for production of value-added products from other biomass components. (Two of these projects (Biorefinery for Polymers and Fuels, Genomics for Enhanced Bio-Products from Sorghum) have been re-scoped to reduce their emphasizes the plant science and increase their focus on the production of value-added bioproducts.)

- *Planning and Analysis for Products*

There is one cross-cutting analysis project ongoing in Products R&D. This project (Identification of Products that can be from Sugars or Syngas) is focused on identifying processes and unit operations that are common to the manufacturing of at least ten products that can be made from sugars or syngas.

2.4.3 Technical Barriers

A simplistic three-step framework for the processing of biomass to products is shown in Figure 30 and embodies the general flow for all biomass-to-products processes. Products R&D will use the platform outputs and other plant components for production of “building blocks” and “secondary chemicals”. These building blocks and secondary chemicals are then used for the manufacturing of a variety of additional intermediates and products that are sold to industry, and consumers. The core of the Products R&D work involves the processing and conversion technology that allows for the cost-effective manufacturing of these building blocks and secondary chemicals to the valuable products that are demanded by the marketplace. The processing and conversion step(s) may involve a number of individual unit operations. In this scheme each step may contain a number of specific technical barriers. Specific performance targets for measuring progress towards overcoming these barriers will vary depending on the specific process and product. Systems analysis is used to reveal the cost and performance targets that are needed to reduce technical risk and speed commercial development. Technical and economic analyses are employed across the program and used by the Stage Gate Reviews to guide the R&D projects.

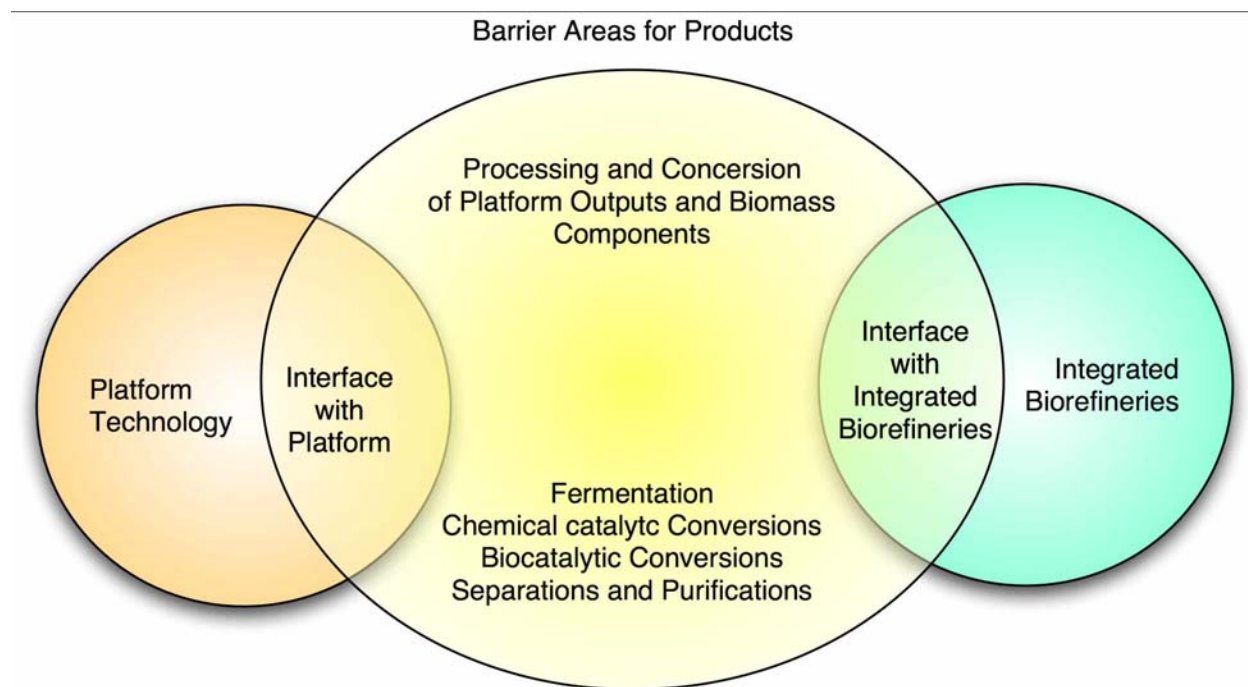


Figure 30: The Interfaces between Platform Technology and Integrated Biorefinery Work and the Area of Products R&D

2.4.3.1 Interfaces with Platforms

The purity and costs of the biomass feed components, and the conversion and separations technology must be evaluated, developed and optimized with an integrated approach to achieve the most

economically viable process. For example, removal of feedstock impurities from the final product could be more feasible than producing a high purity feedstock stream. In general, integrated processes that reduce energy utilization, chemical inputs, and waste stream volumes prove to be more successful. Large capital costs associated with certain separations systems have a negative influence on commercialization. There are series of barriers associated with understanding the interface between.

2.4.3.2 Processing and Conversion

Robust Fermentations

Fermentation is the heart of most bioprocesses. Traditional fermentation involves aqueous phase microbial processing to convert the substrates into fuels and biobased products. While there are currently large-scale commercial ethanol production facilities using fermentations to produce fuel-grade ethanol there are a number of barriers that must be overcome for production of fuels and products from lignocellulosic sugar streams. Many of these barriers are linked to both ethanol production and the production of value-added products. Barriers include a need for improvements in yield, rate, complete conversion and selectivity. New, enhanced and robust microbes need to be developed to ferment all five biomass sugars and deal with this hostile environment to enhance economic viability. Novel bioreactors may offer an opportunity to periodically or continuously remove inhibitors/products from the fermentation. Combinations and assortments of microbes may also be able to carry out the multiple transformations required if such processes can be understood. Bioprocessing of syngas provides a potentially low cost approach to using only moderately clean syngas that may be available at lower cost since bioprocessing may be less sensitive to impurities than typical metal catalysts. All of the fermentation work will need to be carefully integrated with the processes used for production of the fermentation substrates.

There are a number of fundamental issues that must be addressed for improved fermentations. There are barriers and a lack of fundamental understanding that must be overcome including behavior in extreme environments (T, P, pH), gas/liquid two-phase processes, and non-aqueous phase milieu. The use of bioprocessing for commodity chemicals and materials will involve improving the biocatalysts (enzymes or microbes), understanding the impact of the operating environment on the activity of the biocatalysts, better use of existing and advanced reactor designs, and developing appropriate process control.

Improved Catalytic Conversions

Chemical - Nearly 90% of all chemicals produced in the United States involve the use of catalysis. The single most important factor for catalysts performance is selectivity. Yield, which is a product of selectivity and conversion, is also important, however modest conversions can often be managed with recycle. The Program will leverage both the fundamentals and applied aspects of the large body knowledge of Fischer-Tropsch catalysts.

Syngas from biomass has unique aspects in terms of the trade-off between the costs and quality of the syngas. Products R&D for the utilization of this biomass syngas will be closely linked to the syngas clean-up work performed under the Thermochemical Platform. Improved catalysts for the selective conversion of complex biooil mixtures are also needed.

The area of aqueous phase catalysis for biobased products is really in its infancy. There is great potential for improving the selectivity and lowering the costs of catalysis for biomass-derived feedstocks. Some general considerations for heterogeneous catalysis include, lifetime, selectivity, conversion, and weight hourly space velocity. The same considerations need to be addressed in homogenous catalysis with the added dimension of catalyst recovery. The following are specific catalytic barriers to producing products from both categories listed above:

- New catalysts and process for hydrogenation of sugars and oils.

- New catalyst for oxidation, particularly catalysts that can use molecular oxygen as the oxidant.
- New acid catalysts for dehydration.
- Selective dehydroxylation catalysts.
- New, selective hydrogenolysis catalysts for the conversion of alcohol sugars

Fundamental areas of study in chemical catalysis include the development of new catalysts with improved selectivity, understanding catalysis in aqueous systems; knowledge of mass transfer, adsorption, desorption properties; highly porous functionalized supports; and factors that promote more durable catalysts.

Biocatalysis - Biocatalysts include microbial cells and enzymes. Immobilized microbial cells and enzymes are widely used in the pharmaceutical intermediate industry and have an expanding role in the specialty chemical industry. As of yet, these biocatalysts are used sparingly in the commodity chemical industry.

Biocatalysts have the ability to preserve unique properties of biomass, e.g., chirality and hydroxyl groups that are not easily obtained via petrochemical processing. Barriers to the use of biocatalysts for productions of fuels and chemicals include a need for low-cost biocatalysts, a lack of understanding of hybrid chemical/biological process, and unfamiliarity of process chemicals industry in the use of biocatalysts

Fundamental barriers include limited range of chemical transformations, poor interface with organic solvent systems, stability in extreme environments.

Efficient, Cost-Effective Separations

Separations can account for a major fraction (greater than 50 %) of the overall production costs for certain products (power being excluded from analysis) and often are a critical economic barrier to successful commercialization.

Separations strategies are strongly dependent on the target product as well as feedstock impurities. In both chemical and biological processing, byproducts are an issue and for fermentations, the nutrient components add an additional separation barrier.

Biobased products can be liquid phases such as neutral species (alcohols, polyols, etc.) or ionic species (organic acids, amino acids, and other charged species and derivatives) or as gaseous or solid products. All combinations of solid, liquid, and gaseous separation technologies will be required for biobased products. Advanced approaches employing membranes or combinations of reactions and separations are needed to address needs, some at high temperature. Separation needs are often product specific and process integration enhances to opportunities for cost savings.

2.4.3.3 Process, Systems Integration and Validation

The Products R&D work must be highly integrated into overall biorefinery concept. Under this concept there will be a suite of products, dominated by the high volume production of a liquid fuel, and a number of smaller volume, higher value chemicals and materials. With this concept there are two major decisions for the biorefinery that require extensive and continuous analysis and validation. These two decisions are where in the overall process does the feedstock for the fuel or products come from, and how much of the processing and conversion occurs in the biorefinery. The answer to these questions will vary from one biorefinery to another.

In addition to systems integration and validation, there is also a need for new analytical tools and sensors for process development and process control. Such needs are magnified for the complex and varying array of biomass feedstocks flowing into and through biorefinery processes. Analytical tools include both

hardware and data processing software. Improved analytical tools are required for process development and process control. There is also a need for improved analytical tools for fundamental characterization of biomass feedstocks and the interactions between biomass substrates and enzymes and catalysts at the molecular level. A combination of analytical tools will have to be employed to overcome these barriers.

The work breakdown structure for the Products area is organized in projects that correspond to the technical barriers discussed here (see Figure 31).

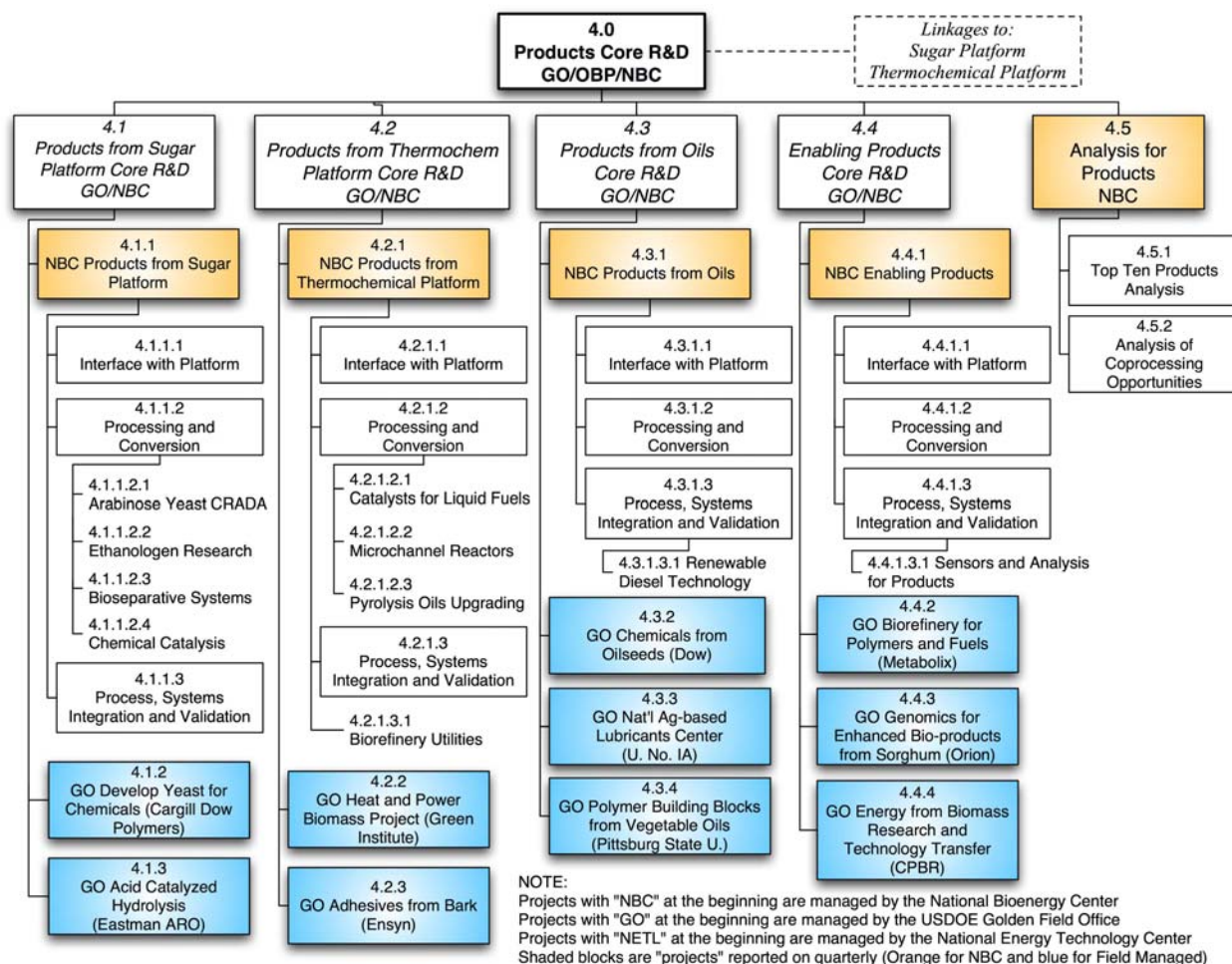


Figure 31: Work Breakdown Structure for the Products Area

2.4.4 Technical Approach

An example of a conceptual biorefinery was shown in Figure 2 (section 1.2). There are a number of unit operations that can produce bioproducts and all of these are part of the Products R&D portfolio.

A petrochemical refinery can be used as a conceptual model for the biorefinery. This model biorefinery may produce a wide variety of specific products depending on the feedstock, geographic location and strategic focus of the organization operating the facility, but there are three major elements that will be common to all biorefineries. First, all biorefineries will produce a significant amount of a fuel product, and process heat and power, and the vast majority will produce value-added bioproducts. Second, there will be a continuous interest in identifying new value-added products that increase the overall profitability of the biorefinery. Changes in the composition, cost and availability of the biomass feedstocks,

improvements in the processing and conversion technology, and market changes will dictate how these new products are integrated into the biorefinery. Finally, the biorefinery will not produce any solid wastes, and will produce a minimum amount of liquid and gaseous wastes. Solid, and some liquid, residues will be used for production of heat and power.

To provide a balanced portfolio the technical approach involves a two-prong strategy. Strategy one involves highly leveraged interactions with industry that is characterized by cost-share and is typically done with a team of performers. Strategy two involves R&D to reduce the uncertainty in approaches that address specific technical barriers.

Strategy 1 Support to industry in the development of products

This strategy is characterized by significant industry involvement or leadership including cost share, by use of feedstocks provided by existing infrastructure, and with involvement from other technology providers such as laboratories, universities, and small businesses. Projects conducted under this strategy are commonly selected from competitive RFPs and Congressionally directed appropriations. Many of these projects are developing and demonstrating biobased products for integrated biorefineries and for specific commercial markets. Strategy 1 projects will allow OBP to meet its goals of establishing the viability of two commodity scale chemicals or materials co-produced in an integrated biorefinery by 2005 and four by 2010.

Rationale – Demonstrates integrated processing for the biorefinery concept, and can validate technology and process choices for the biorefinery concept. The focus will be on integrated processes that produce fuels and value-added products that have potential markets to support a significant number of biorefineries.

Strategy 2: Supporting OBP in the pursuit of high-risk/high-impact technology that is broadly applicable across all the platform outputs currently available (or envisioned)

This strategy is characterized by performance by DOE laboratories with appropriate involvement of other technology providers such as universities. Industrial cost share is related to the structure of the project and ownership of intellectual property. These projects will be focused on developing the fundamental understanding and knowledge of barriers that are common to many processes used to produce biomass products. These projects will also insure that all biomass components from a particular process are completely utilized and emissions are minimization. These projects have industrial review and guidance and will develop technology to support Strategy 1 projects and development of potential candidates for new Strategy 1 R&D.

Rationale - Cross-cutting R&D can provide technology that reduces risk and cost, and shortens development time for multiple projects within the products area. Work under this strategy will also assist in prioritizing the requirements for different platform outputs and engages a wide range of industrial stakeholders. This strategy will also insure that all biomass feedstock components are efficiently utilized in OBP supported biorefineries.

The technical approach for specific byproducts is summarized below.

- ***Biobased Fuels for Transportation Markets***

Production of ethanol from mixed sugars is key for the biobased fuels industry. There are well-developed, commercially available technologies for producing ethanol from high quality glucose streams, but there is no commercially viable technology for producing ethanol from less expensive, more complex lignocellulosic sugar streams. The biorefinery will have to effectively utilize a mixture of 5 or more individual sugars, and these streams also contain phenolic and extractive components that can inhibit ethanol fermentation. Integration and utilization of lignin and protein solid waste streams will be key for the commercial viability of lignocellulosics ethanol biorefineries.

Similar to production of ethanol from clean glucose, production of Fischer-Tropsch liquids from clean natural gas-derived syngas is a well-developed, commercial technology. But the biorefinery must be able to produce Fischer-Tropsch liquids from complex, biomass-derived syngas, which is not a commercially viable technology. This is because of the tars and impurities contained in biomass-derived syngas will deactivate the catalysts that are required for the conversion of syngas to Fischer-Tropsch liquids. The Products R&D activities are focused on evaluating catalysts for the destruction of the tars and other impurities, and for the evaluation of commercially available catalysts with biomass-derived syngas streams of varying quality.

Biooils are produced by the thermal depolymerization of a variety of biomass sources. Thermal depolymerization processes are very robust and can be conducted under a wide variety of reaction conditions, e.g., reaction times, temperatures, pressures, with or without high moisture contents or catalysts, and accommodate a wide variety of feedstocks or process residues. Biooils are complex mixtures that can be produced at a low cost and used directly for some fuel application or upgraded into more valuable products. These upgrading processes are of interest for Products R&D.

Production of Biodiesel from oilseeds and animal by-products is a well-developed technology. To increase Biodiesel production volumes will require new, value-added uses the glycerol that is generated during biodiesel production, and new technology for production of biodiesel for low cost feedstocks. The OBP is interested in both of these barrier areas.

Production of fuel additives, oxygenates and hydrogen will require the evaluation commercially available catalysts with real biomass derived syngas streams.

- *Biobased Products for Chemicals and Materials Markets*

The suite of value-added bioproducts projects included in the Products R&D portfolio can be classified by the strategic pathway. Projects conducted under strategic pathway 1 will generally be defined industrial partners responding to competitive solicitations. Depending on the focus of the competitive solicitation and the technology expertise and market interests of the company(s) the specific products may vary widely and be derived from any of the biomass components. Thus it is likely that most of these projects will focus on feedstocks and technologies that are nearer to commercialization. As witnessed by the current portfolio of projects these will tend to technologies that use relatively clean sugars, more valuable thermochemical outputs and crop oils.

The second strategic pathway includes precompetitive Products R&D activities that are focused on overcoming barriers that are common to many products. Barrier areas that are common to a number of bioproducts were identified by the “Top Ten” analysis looking at biobased chemicals and materials from sugars and syngas. The initial phase of the Top Ten analysis has revealed several barrier areas that are common to products from sugars and syngas. Additional analysis is required for other thermochemical outputs, lignin and emerging feedstocks. The common barrier areas include ?????. Projects conducted under this strategy will also focus on the more complex, less attractive biomass components, e.g., lignin, protein, and char. These projects are needed to insure that advanced biorefineries supported by OBP are commercially competitive, energy efficient and environmentally benign.

- *Heat and Power for the Biorefinery and Utility Markets*

The Biorefinery will have significant heat and power requirements. The efficient utilization of all residue streams can help satisfy some or all of the heat and power requirements. In some cases there will be an opportunity to export heat and power.

Biopower is a commercially proven electricity generating option in the United States. The next generation of stand-alone biopower production will substantially mitigate the high costs and efficiency disadvantages through biomass cofiring in coal-fired power stations, through the introduction of high-

efficiency gasification combined cycle systems, and through efficiency improvements in direct combustion systems. Technologies presently at the research and development stage, such integrated gasification fuel cell systems, and modular systems are expected to be competitive in the future.

- *Planning and Analysis for Products*

Each project will contain it's own analysis and planning work that are specific to the technology under development. This activity is crosscutting and supports the entire Products R&D area. Products R&D is somewhat unique in the variety of products can be produced from biomass feedstocks. In the case of fuels, and power, there are a limited number of potential products, e.g., ethanol, Fischer-Tropsch liquids, biodiesel, hydrogen, and heat and electricity. But in the case of chemicals and materials there are hundreds of products that can be made. The key is to identify the products that allow OBP to help EERE met its goals of reducing dependence on foreign oil and helping to create the new, domestic bioindustry. These products should be, or have the potential to enter into, large volume (greater than 1 billion pounds) chemical markets. The goal of this work is not to pick the best targets for DOE to pursue, this is industries' role, the goal is to identify processes and unit operations that are common to many of the products for precompetitive work to support many projects focused on specific products. This first study has been limited to products that can be made from sugars and syngas. Additional studies will evaluate products that can be made from other biomass feedstocks.

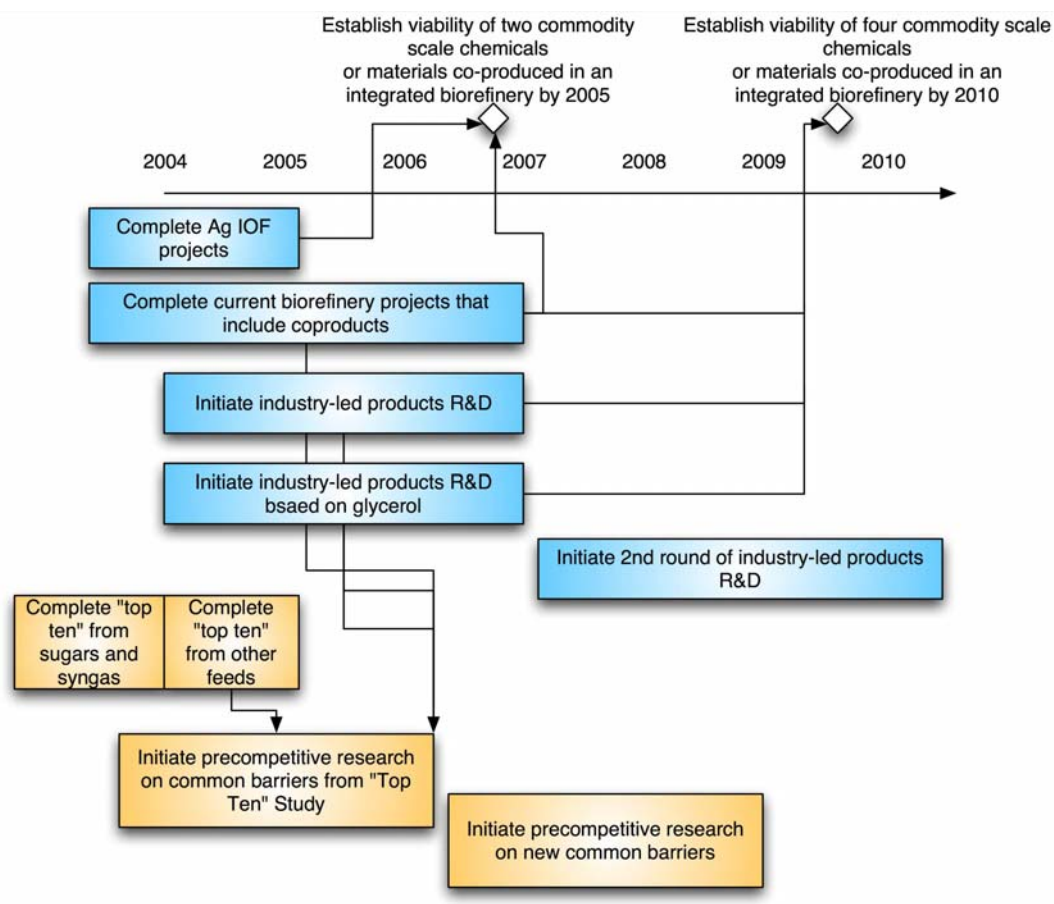


Figure 32: Relationship of Products R&D

In the Stage Gate context the activities conducted under Strategy 1 are on the “commercial line” and activities conducted under Strategy 2 are on the “research line”. The Stage Gate process can be applied to both strategies and provide a means to address the highest priority technology pathways that will

overcome technical barriers. OBP efforts can be leveraged from platform R&D and focus on specific pathways that will yield enabling technologies for both products and platform R&D.

Gantt charts for the Products area are shown in Figure 33 through Figure 37.

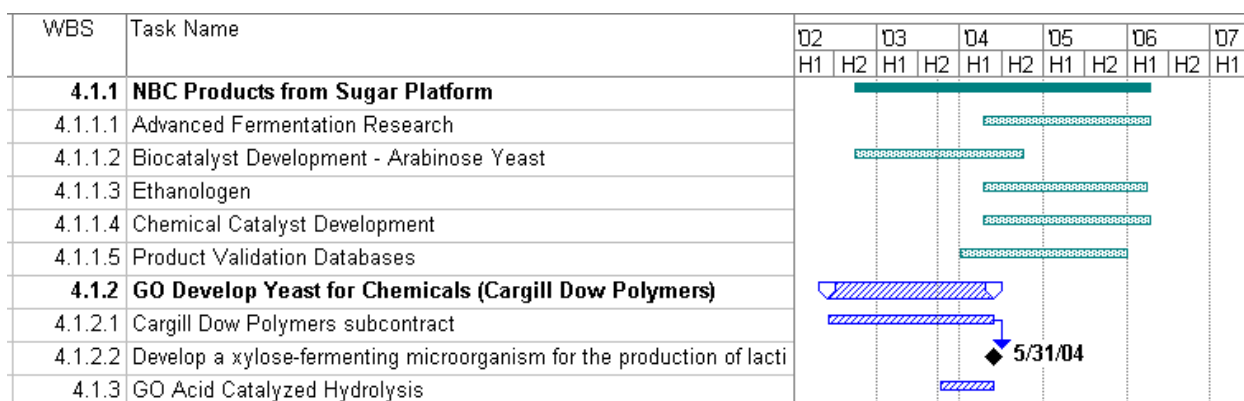


Figure 33: Biomass Program Activities for Products from Sugars

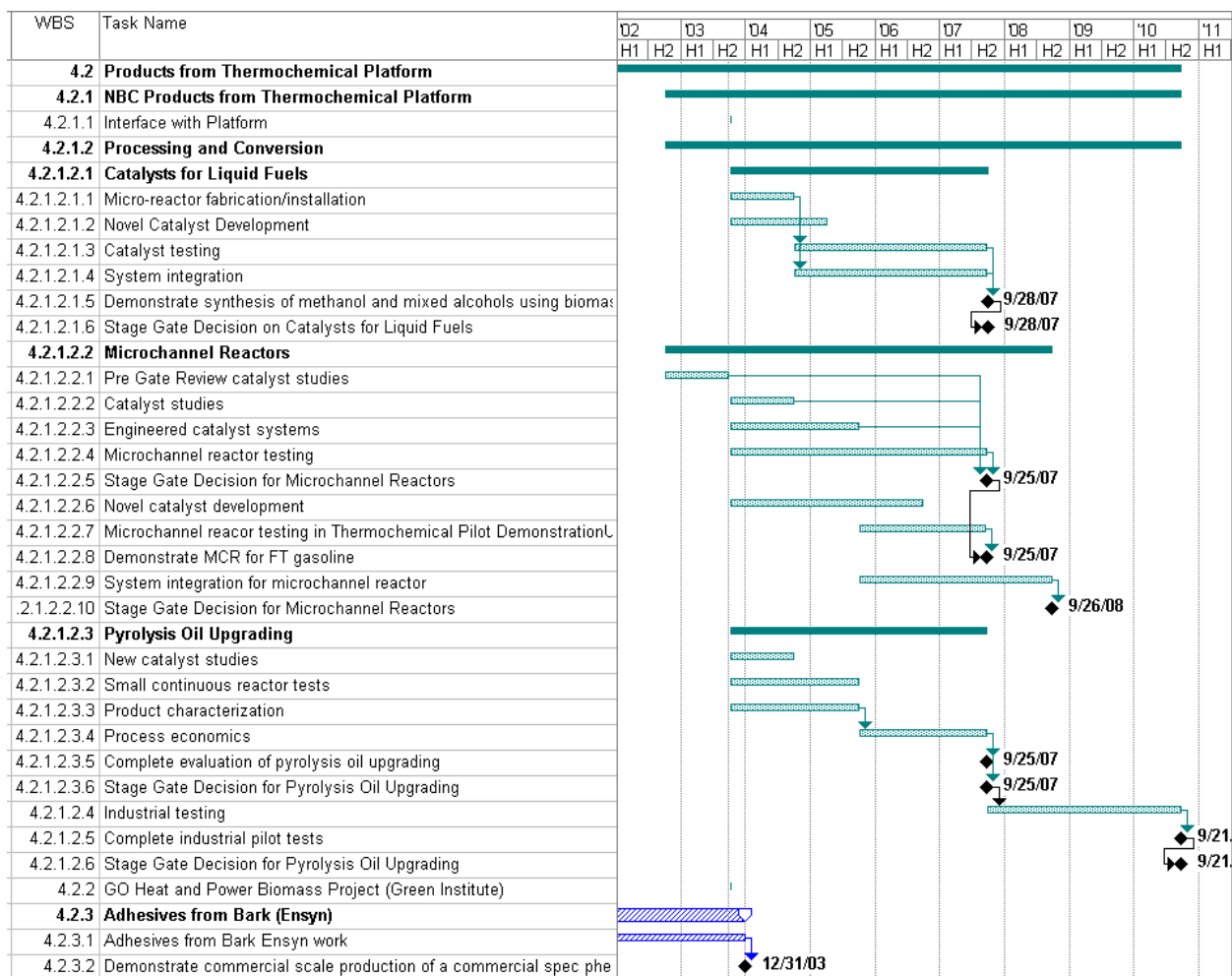


Figure 34: Biomass Program Activities for Products from the Thermochemical Platform

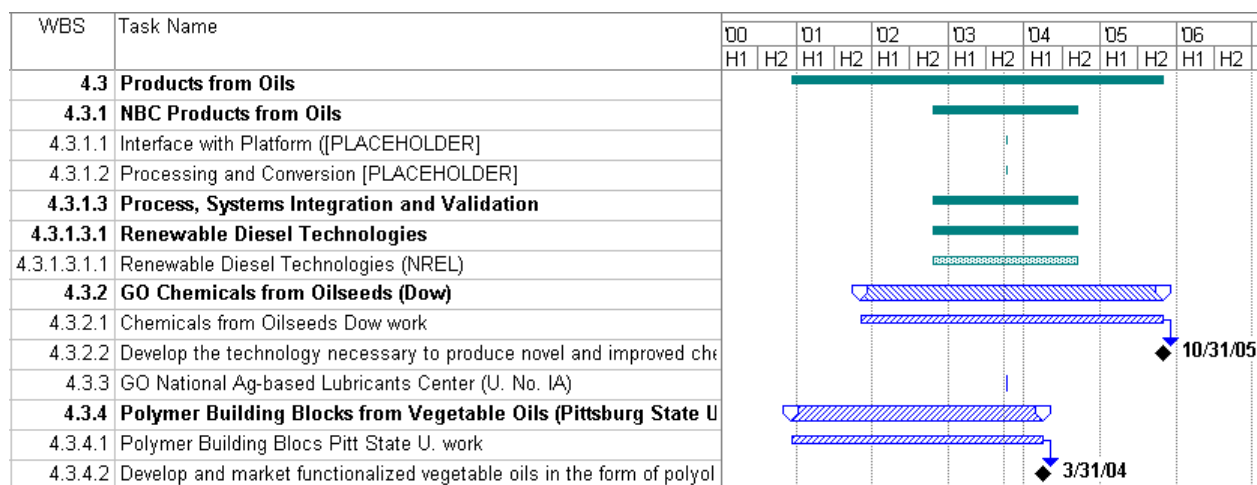


Figure 35: Biomass Program Activities for Products from Oils

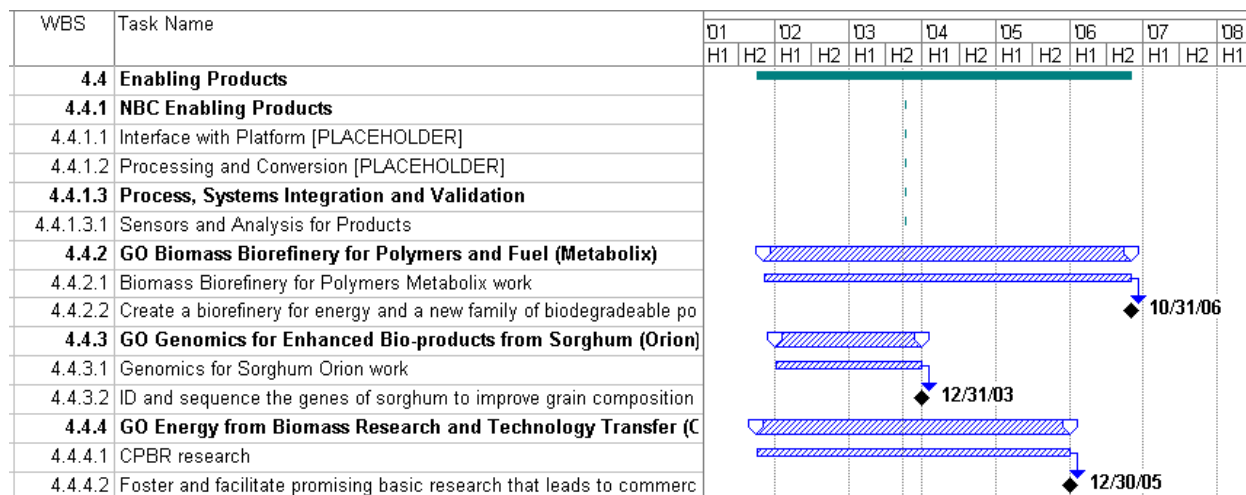


Figure 36: Biomass Activities for Enabling Products

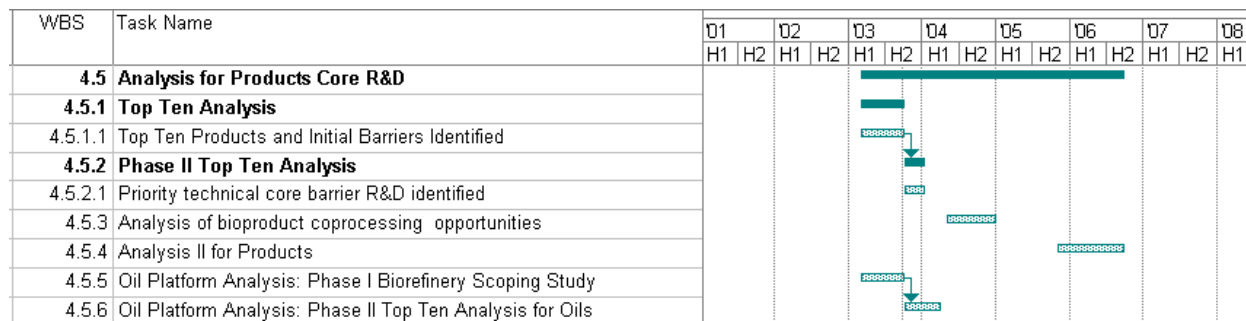


Figure 37: Biomass Activities for Products Analysis

2.4.5 Resource Allocation Plan

The resource allocation plan for products is presented in Figure 38 and Table 16.

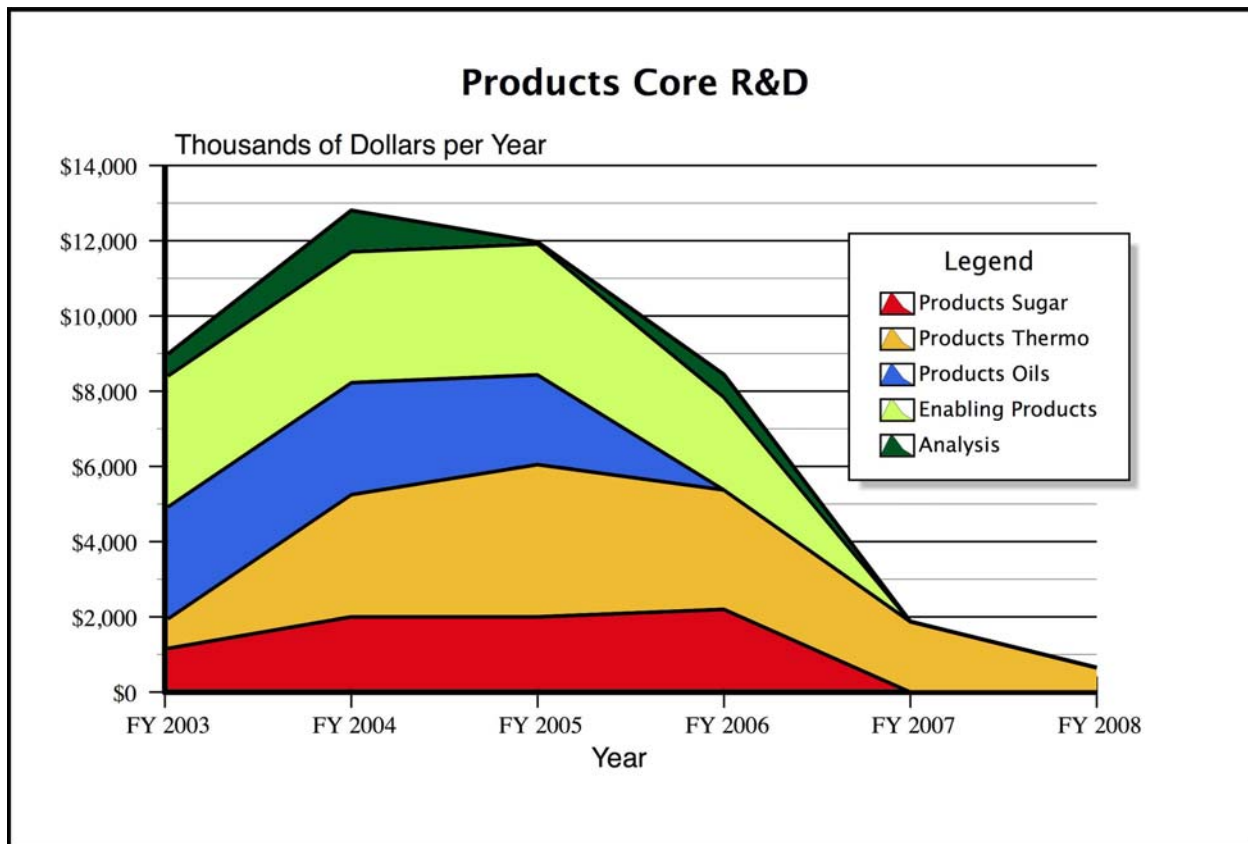


Figure 38: Resource Allocation Plan for Products Area

2.4.6 Products Area Projects and Milestones

Table 17 summarizes all of the projects included in the Products area, organized according to major barrier areas for the platform. Information is also included on the specific barriers addressed by each project and their milestones.

Table 16: Resource Allocation Plan for Products Area

WBS	Title	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
4	Products	\$1,380	\$35,478	\$8,987	\$12,807	\$11,965	\$8,441	\$1,875	\$650
4.1	Products from Sugar Platform	0	1161	\$1,161	\$2,000	\$2,000	\$2,200	\$-	\$-
4.1.1	NBC Products from Sugar Platform								
4.1.1.1	Interface with Sugar Platform								
4.1.1.2	Processing and Conversion		0	\$-	\$1,000	\$1,000	\$1,100	\$-	\$-
4.1.1.2.1	Arabinose Yeast CRADA				\$700	\$700	\$800		
4.1.1.2.2	Ethanologen Research				\$300	\$300	\$300		
4.1.1.2.3	Bioseparative Systems								
4.1.1.2.4	Chemical Catalysis								
4.1.1.3	Process, Systems Integration and Validation								
4.1.2	GO Develop Yeast for Chemicals (Cargill Dow Polymers)		1161	\$1,161					
4.1.3	GO Acid Catalyzed Hydrolysis								
4.2	Products from Thermochemical Platform	\$788	\$788	\$788	\$3,250	\$4,050	\$3,175	\$1,875	\$650
4.2.1	NBC Products from Thermochemical Platform								
4.2.1.1	Interface with Thermochemical Platform								
4.2.1.2	Processing and Conversion								
4.2.1.2.1	Catalysts for Liquid Fuels				\$350	\$750	\$475	\$475	\$50
4.2.1.2.2	Microchannel Reactors				\$1,000	\$1,500	\$1,400	\$100	\$100
4.2.1.2.3	Pyrolysis Oil Upgrading				\$700	\$500			
4.2.1.2.4	Industrial testing								
4.2.1.2.5	Complete industrial pilot tests								
4.2.1.2.6	Stage Gate Decision for Pyrolysis Oil Upgrading								
4.2.1.3	Processing, Systems Integration and Validation								
4.2.1.3.1	Biorefinery Utilities				\$1,200	\$1,300	\$1,300	\$1,300	\$500

WBS	Title	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
4.2.2	Heat and Power Biomass Project (Green Institute)								
4.2.3	Adhesives from Bark (Ensyn)	788	788	\$788					
4.3	Products from Oils	592	2976	\$2,976	\$2,976	\$2,384			
4.3.1	NBC Products from Oils								
4.3.1.1	Interface with Platform ([PLACEHOLDER]								
4.3.1.2	Processing and Conversion [PLACEHOLDER]								
4.3.1.3	Process, Systems Integration and Validation								
4.3.1.3.1	Renewable Diesel Technology								
4.3.2	GO Chemicals from Oilseeds (Dow)		2384	\$2,384	\$2,384	\$2,384			
4.3.3	GO National Ag-based Lubricants Center (U. No. IA)								
4.3.4	Polymer Building Blocks from Vegetable Oils (Pittsburg State U.)	592	592	\$592	\$592				
4.4	Enabling Products		30553	\$3,481	\$3,481	\$3,481	\$2,466		
4.4.1	NBC Enabling Products								
4.4.1.1	Interface with Platform [PLACEHOLDER]								
4.4.1.2	Processing and Conversion [PLACEHOLDER]								
4.4.1.3	Process, Systems Integration and Validation								
4.4.1.3.1	Sensors and Analysis for Products								
4.4.2	GO Biomass Biorefinery for Polymers and Fuel (Metabolix)		2466	\$2,466	\$2,466	\$2,466	\$2,466		
4.4.3	GO Genomics for Enhanced Bio-products from Sorghum (Orion)		27072						
4.4.4	GO Energy from Biomass Research and Technology Transfer (CPBR)		1015	\$1,015	\$1,015	\$1,015			
4.5	Analysis for Products			\$581	\$1,100	\$50	\$600		
4.5.1	Top Ten Products Analysis			\$581	\$1,100	\$50	\$600		

Table 17: Alignment of Projects, Milestones and Technical Barriers for the Products Core R&D Area

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
Products from Sugar Platform GO/NBC	4.1.1.1 Interface with Platform		
	4.1.1.2 Processing and Conversion		
	4.1.1.2.1 Arabinose Yeast CRADA	<ul style="list-style-type: none"> • Fermentation and biocatalysis. • Focused on production of fuel ethanol from lignocellulosics sugar streams (five carbon sugars) 	<p>8/30/04: Demonstrate arabinose anaerobic fermentation in a yeast.</p> <p>8/30/05: Develop commercial product yield, production rate, and product titer in yeast fermentation of arabinose.</p> <p>9/30/06: Integrate arabinose fermentation with the best available xylose fermentation in yeast.</p>

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	4.1.1.2.2 Ethanologen Research	<ul style="list-style-type: none"> Fermentation and biocatalysis Production of fuel ethanol from mixed lignocellulosics sugar streams with inhibitory compounds 	<p>7/30/04: Place a competitive subcontract for a substantial metabolic model of <i>Saccharomyces cerevisiae</i></p> <p>9/30/05: Evaluate prediction(s) for fermentation optimization of <i>S. cerevisiae</i> by the metabolic model for improving a ethanol fermentation.</p> <p>7/30/06: Evaluate prediction(s) for genetic engineering of <i>S. cerevisiae</i> by the metabolic model to improve a key parameter of ethanol fermentation.</p> <p>9/30/06: Place subcontract extension for second iteration of Metabolic model evaluation.</p> <p>7/30/07: Second round: Evaluate prediction(s) for fermentation optimization of <i>S. cerevisiae</i> by the metabolic model for improving a ethanol fermentation.</p> <p>7/30/08: Second round: Evaluate prediction(s) for genetic engineering of <i>S. cerevisiae</i> by the metabolic model to improve a key parameter of ethanol fermentation.</p>
	4.1.1.2.3 Bioseparative Systems	<ul style="list-style-type: none"> Enhanced separations 	
	4.1.1.2.4 Chemical Catalysis	<ul style="list-style-type: none"> Chemical catalysis 	
	4.1.1.3 Process, Systems Integration and Validation	<ul style="list-style-type: none"> 	

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	4.1.2 GO Develop Yeast for Chemicals (Cargill Dow Polymers)	<ul style="list-style-type: none"> Fermentation and biocatalysis 	Task 1:Improve xylose to lactate fermentation of Strain M1 Task 2:Improve xylose to lactate fermentation of Strain N1 Task 3:Construction of xylose to lactic fermenting Pichia stipitis as benchmark strain Task 4:Screen for and isolate eukaryotic xylose isomerases Task 5:Construction of xylose to lactate fermenting microorganisms utilizing novel XI(s) Task 6:Rough biochemical characterization of chosen xylose pathway enzymes Task 7:Tools for genetic engineering of most promising strains Task 8:Genetic engineering of new host species for xylose to lactate fermentation Task 9: Improvement of most promising strains from Tasks 1, 2, 5 or 8
	4.1.3 GO Acid Catalyzed Hydrolysis (Eastman ARO)	<ul style="list-style-type: none"> Chemical catalysis 	
NBC Products from Thermochemical Platform	4.2.1.1 Interface with Platform		
	4.2.1.2 Processing and Conversion		
	4.2.1.2.1 Catalysis for Liquid Fuels	<ul style="list-style-type: none"> Chemical catalysis Increase the amount of renewable transportation fuels and chemicals to offset the use of petroleum. 	9/2007 Demonstrate synthesis of methanol and mixed alcohols using biomass derived syngas

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	4.2.1.2.2 Microchannel Reactors	<ul style="list-style-type: none"> Chemical catalysis Increase the amount of renewable transportation fuels and chemicals to offset the use of petroleum. 	10/2006 Demonstrate microchannel reactor for FT gasoline
	4.2.1.2.3 Pyrolysis Oils Upgrading	<ul style="list-style-type: none"> Chemical catalysis 	
	4.2.1.3 Process, Systems Integration and Validation		
	4.2.1.3.1 Biorefinery Utilities	<ul style="list-style-type: none"> Process, systems integration and validation The lack of reliable performance information (including process configuration optimization), emissions, and efficiency data for various integrated gasifier-power systems required to make intelligent decisions regarding the optimum configuration of the combined heat and power (CHP) unit of biorefineries. 	2/2004 Complete microturbine testing on reformed syngas 9/2004 Complete baseline testing of SOFC on natural gas and bottled syngas 9/2005 Complete integrated TCPDU-SOFC testing 9/2006 Complete integrated TCPDU-SOFC testing with separated anode exhaust 9/2007 Complete SOFC scale-up and integration into syngas platform 12/2008 Complete 250 hours testing of integrated syngas platform
	4.2.2 Heat and Power Biomass Project (Green Institute)		

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	4.2.3 Adhesives from Bark	<ul style="list-style-type: none"> Process, systems integration and validation Demonstrate the performance of adhesives containing biooils derived from bark or forest residues. 	12/2003 Complete characterization of Pyrolysis Products 12/2003 Complete Resin Formulation Development 12/2003 Complete commercial Trial Production Runs of OSB 12/2003 Perform Wood-based Natural Resin & Bark-based Comparison 12/2003 Complete technical feasibility of Bio-Oil Co-Products 12/2003 Complete technical feasibility of Carbon Co-Products
Products from Oils GO/NBC	4.3.1.1 Interface with Platform		
	4.3.1.2 Processing and Conversion		
	4.3.1.3 Process, Systems Integration and Validation		
	4.3.1.3.1 Renewable Diesel Technology	<ul style="list-style-type: none"> Chemical catalysis and process, system integration and validation 	
	4.3.2 GO Chemicals from Oilseeds (Dow)	<ul style="list-style-type: none"> Processing and conversion Chemical and biocatalysis 	Task 1: Plant Science Task 2: Production Task 3: Processing Task 4: Utilization
	4.3.3 GO National Agricultural Based Lubricants Center	<ul style="list-style-type: none"> Process, System Integration and Validation 	

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	4.3.4 GO Polymer Building Blocks from Vegetable Oils (Pittsburg hState U)	<ul style="list-style-type: none"> Chemical Catalysis and Process, System Integration and Validation 	Establish feasibility of making polyols from soy oil Establish feasibility of making polycarboxylic acid from soy oil Establish feasibility of making polyamines from soy oil established Establish technical and commercial feasibilities, complete pilot scale-ups
Enabling Products GO/NBC	4.4.1.1 Interface with Platform		
	4.4.1.2 Processing and Conversion		
	4.4.1.3 Process, Systems Integration and Validation		
	4.4.1.3.1 Sensors and Analysis for Products	<ul style="list-style-type: none"> Process, System Integration and Validation 	

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	4.4.2 GO Biorefinery for Polymers and Fuels (Metabolix)	<ul style="list-style-type: none"> Process, System Integration and Validation 	<p>Nuclear Transformation of Plastid Targeted PHB Enzymes into Switchgrass.</p> <p>Develop Plastid Encoded PHB Production Systems.</p> <p>Develop Inducible PHB Production Systems.</p> <p>Introduce Plastid Encoded PHB Production Systems into Switchgrass.</p> <p>Develop PHA Copolymers.</p> <p>Develop Optimized Recovery processes in a biorefinery context.</p> <p>Life Cycle Analysis.</p> <p>Investigate Applications for PHAs.</p> <p>Management and Reporting.</p>

Technical Barrier Area	Project	Specific Technical Barriers Addressed	Milestones
	4.4.3 Go Genomics for Enhanced Bio-products from Sorghum (Orion)	<ul style="list-style-type: none"> Process, System Integration and Validation 	12/2003: identify and sequence the genes of sorghum, discover the links between specific genes and the composition of grain, use plant breeding to improve the grain composition, and identify a potential portfolio of processed output products
	4.4.4: Center for Plant Biotechnology Research	<ul style="list-style-type: none"> Broad ranging from feedstock production to use 	12/2004: Conduct research in plant biotechnology and other bio-based technologies
	4.5.1 Top Ten Products Analysis		9/2003 Top Ten products and general technical barriers identified 4/2004 Prioritized technical barriers for products identified 8/2004 Potential for biorefinery options with feedstocks from range or marginal land 8/2004 Potential for chemical products from citrus residues Analysis II for products
Analysis for Products NBC	4.5.2 Analysis of Coprocessing Opportunities		

2.5 Integrated Biorefineries

According to the Office of Biomass Program's Multi-Year Plan (MYP), "a biorefinery processes biomass into value-added product streams." In theory, anything that uses biomass and makes more than one product is a biorefinery. This very simple definition captures a wide range of existing, emerging and advanced process concepts. Examples of existing biorefineries include corn processors and pulp and paper mills.

The name biorefinery purposely evokes visions of today's petroleum refinery. In a modern petroleum refinery complex, the largest volume product is liquid fuel. However, the key to its profitability lies in the small percentage of value-added petrochemicals that it makes. Similarly a biorefinery will seek to produce the optimum combination of fuels, power and heat/energy products to produce the greatest financial return.

The following definition of a biorefinery was recently legislated by Congress in the 2002 Farm Bill:

"The term 'biorefinery' means equipment and processes that—

- (A) convert biomass into fuels and chemicals; and
- (B) may produce electricity."

For the purposes of this plan, the concept of a biorefinery is expanded to embody a facility that uses biomass to make a slate of fuels and chemicals in order to maximize the value of the biomass, and thereby maximize the financial return to the producer. The notion of maximizing the value derived from biomass through an optimal slate of products is the key to understanding why the biorefinery is the central strategy for the Biomass Program.

2.5.1 Technical Goals and Objectives

The goal of the Integrated Biorefinery program area is to support the establishment of integrated biorefineries through partnerships with industry and academia. This goal is the culmination of the work being done in the core R&D areas. The Integrated Biorefinery is where the development of the platforms and of new capabilities for products are brought together in a fully integrated operation. The objectives of this area, therefore, reflect four out of the six major outcomes defined for the program in the MYPP. They include:

- Complete analysis of biorefinery options by 2004 that identifies the most promising processes, products.
- Complete technology development necessary to enable start-up demonstration of a biorefinery producing fuels, chemicals and power by 2007.
- Demonstrate a fully integrated black liquor gasification system for heat and power production at a commercial pul mill by 2009
- Help U.S. industry to establish the first large-scale sugar biorefinery based on agricultural residues by 2010.

2.5.2 Programmatic Status

In 2002 the OBP awarded funds to six major biorefinery development projects that are focused on new technologies for integrating the production of biomass-derived fuels and other products in a single facility. The emphasis is on using new or improved processes to derive products such as ethanol, 1,3 propandiol, polylactic acid, isosorbide, and various other chemicals. A synopsis of these projects is given in Table 18 below. Milestones for these projects are highlighted in Table Table 20. A more complete multi-year project description is included in the Appendix.

Mill-scale validation activities are planned for a large black liquor steam reforming gasification system in Big Island, Vermont, and another large biomass gasification system in Louisiana. Georgia-Pacific, Boise-Cascade, Gas Technology Institute (GTI), MTCL, several national laboratories (NETL, ANL, ORNL), universities, A&E firms, and equipment suppliers are participating. The outcome will be two or more operating commercial-scale black liquor and biomass gasifiers with validated performance to support implementation in future biorefineries.

A number of projects are already underway to develop technologies for entirely new industrial bioproducts from corn-derived sugars, sorghum, and vegetable oils. The activities conducted range from fundamental research on feedstock-specific catalysts to integration of new technology into the biorefinery. Products are diverse, ranging from corn- and oil-based polymers to chemicals such as malonic acid and Isosorbide. Partners include national laboratories (NREL, ORNL, PNNL, SNL), individual chemicals, food and enzyme manufacturers, universities, and trade associations such as the Iowa Corn Promotion Board, United Soybean Board, and the National Corn Growers Association.

Table 18: FY02 Integrated Biorefinery Solicitation Projects

2nd Generation Dry Mill Biorefinery - Broin and Associates, Inc. of South Dakota will enhance the economics of existing ethanol dry mills by increasing ethanol yields and creating additional co-products. Broin estimates that its process will increase ethanol output at existing plants by approximately 10-20% by 2006.
New Biorefinery Platform Intermediate - Cargill, Inc. of Minnesota will develop a bio-based technology to produce a wide variety of products based on 3-HP acid, which is produced by the fermentation of carbohydrates.
Integrated Corn-based Bio Refinery (ICBR) - Delaware's E.I. du Pont de Nemours & Co., Inc. (DuPont) will build a biobased production facility to convert corn and stover into fermentable sugars for production of value-added chemicals.
Making Industrial Bio-refining Happen - Based in Minnesota, Cargill Dow LLC National will develop and validate process technology and sustainable agricultural systems to economically produce sugars and chemicals such as lactic acid and ethanol.
Advanced Biorefining of Distiller's Grain and Corn Stover Blends - Abengoa Bioenergy Corporation, with plants in Kansas, Nebraska and New Mexico, will develop a novel biomass technology to utilize distiller's grain and corn stover blends to achieve significantly higher ethanol yields while maintaining the protein feed value.
Separation of Corn Fiber and Conversion to Fuels and Chemicals - The National Corn Growers Association, based in Missouri, will develop an integrated process for recovery of the hemicellulose, protein, and oil components from corn fiber for conversion into value-added products.

2.5.3 Technical Barriers

The barriers to developing and making this core technology available have largely been addressed in the technical plans related to the specific core technology needs for the sugar platform, the syngas platform and the conversion of biomass intermediates into products. Nevertheless, there are a number of barriers that are peculiar to the goal of demonstrating and deploying commercially successful biorefinery technology. These include:

- The challenge of end-to-end, feed-to-product, process integration

- The risk of pioneer technology

The Program addresses the issue of the risk of deploying new technology by helping to buy down the high cost of the later stages of commercial development, in particular stage 3 process development and stage 4 commercial demonstration. A number of the projects included in this area are cost shared efforts to develop specific applications for utilizing biomass.

However, in these integrated demonstrations a primary concern for project partners is the protection of their own intellectual property position. The need to closely protect know-how developed by each partner could lead to the need for each new player in the industry to independently solve many of the same barriers, effectively limiting the impact that the Program's investments in these project can have on its goal of establishing a new bioeconomy. The Program's core R&D work can mitigate this problem by providing information that is widely available to anyone interested in becoming a part of this new industry. However, research in the core program could be seen as impeding and negatively impacting the business goals of our partners if it is too closely related to their work. Thus, the Program must carefully differentiate between defining research related to barriers that is general enough in nature to support the needs of the industry as a whole, and yet contribute to the overall reduction of risk for DOE's industry partners.

2.5.4 Technical Approach

The portfolio of projects for this area of the program, as shown in the work breakdown structure (see Figure 40), reflects a range of existing and emerging biorefinery opportunities. These projects include both sugar platform-based biorefineries and thermochemical biorefineries.

2.5.5 Resource Allocation Plan

Table 19 and Figure 39 summarize the resource plan for the integrated biorefinery projects.

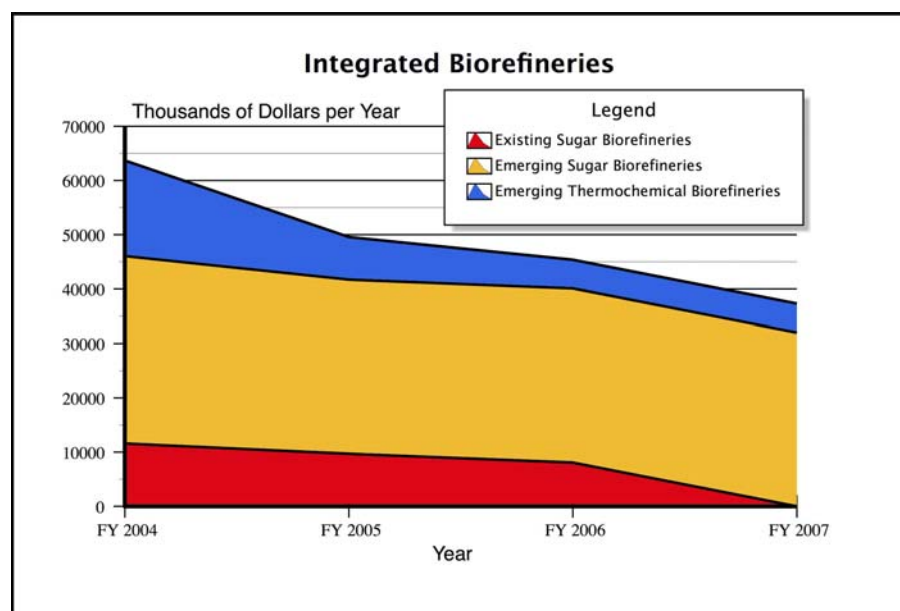


Figure 39: Resource Allocation Plan for Integrated Biorefineries

2.5.6 Integrated Biorefineries Projects and Milestones

Table 20 summarizes all of the projects included in the Integrated Biorefinery area, organized according to major barrier areas for the platform. Information is also included on the specific barriers addressed by each project and their milestones.

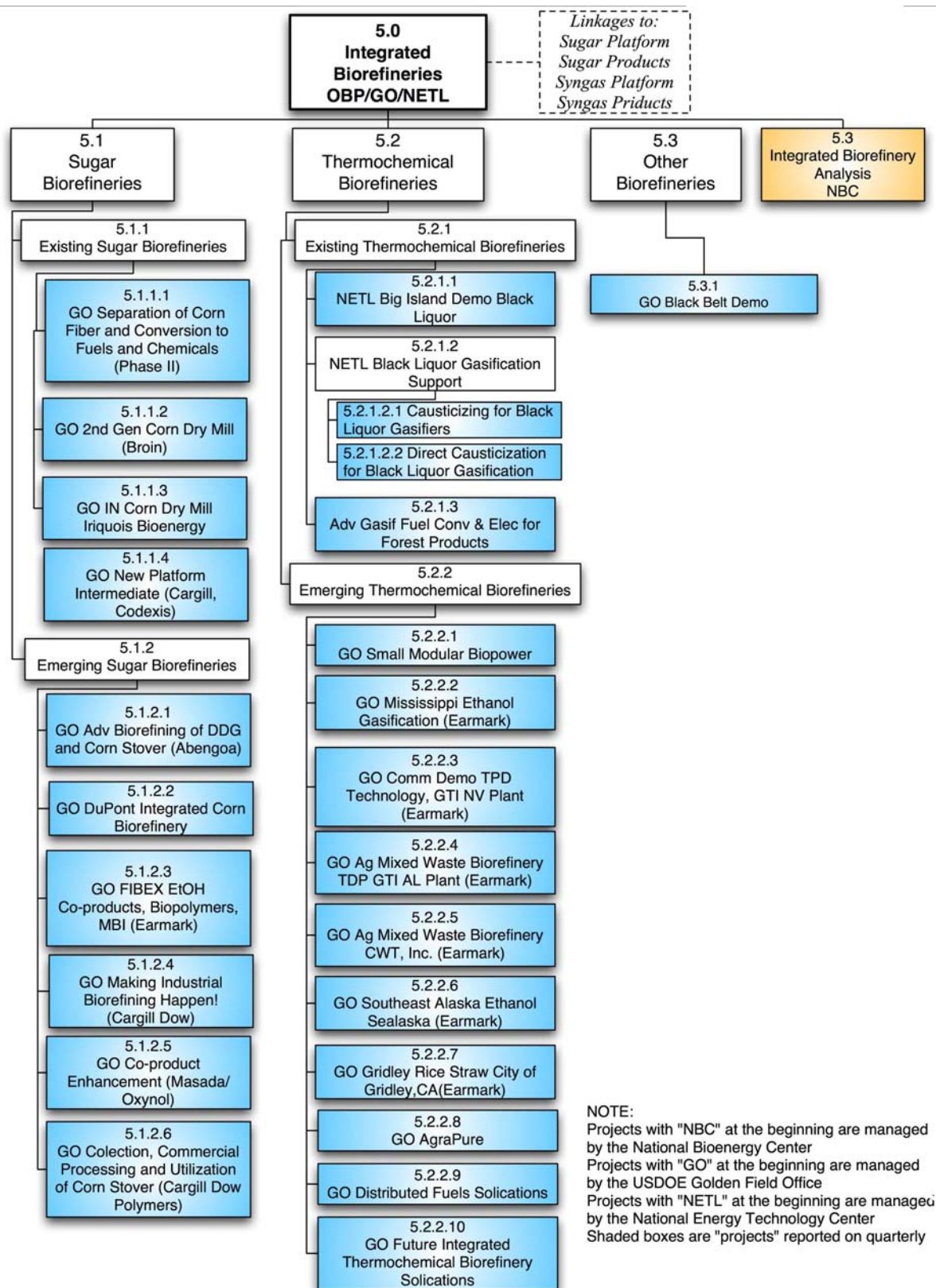


Figure 40: Work Breakdown Structure for the Integrated Biorefineries Area

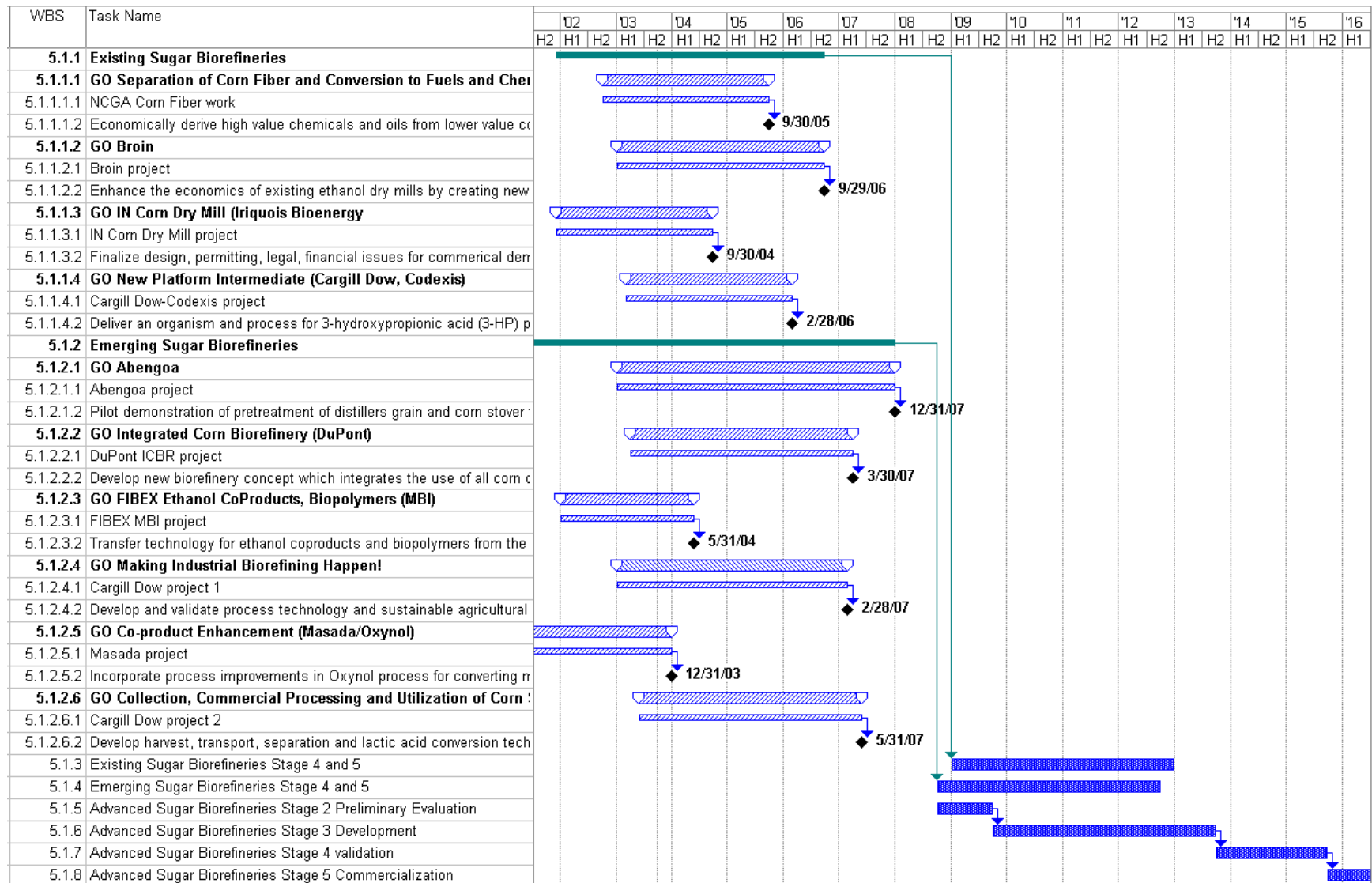


Figure 41: Biomass Program Industry Partnership Activities in Support of Integrated Sugar Biorefineries

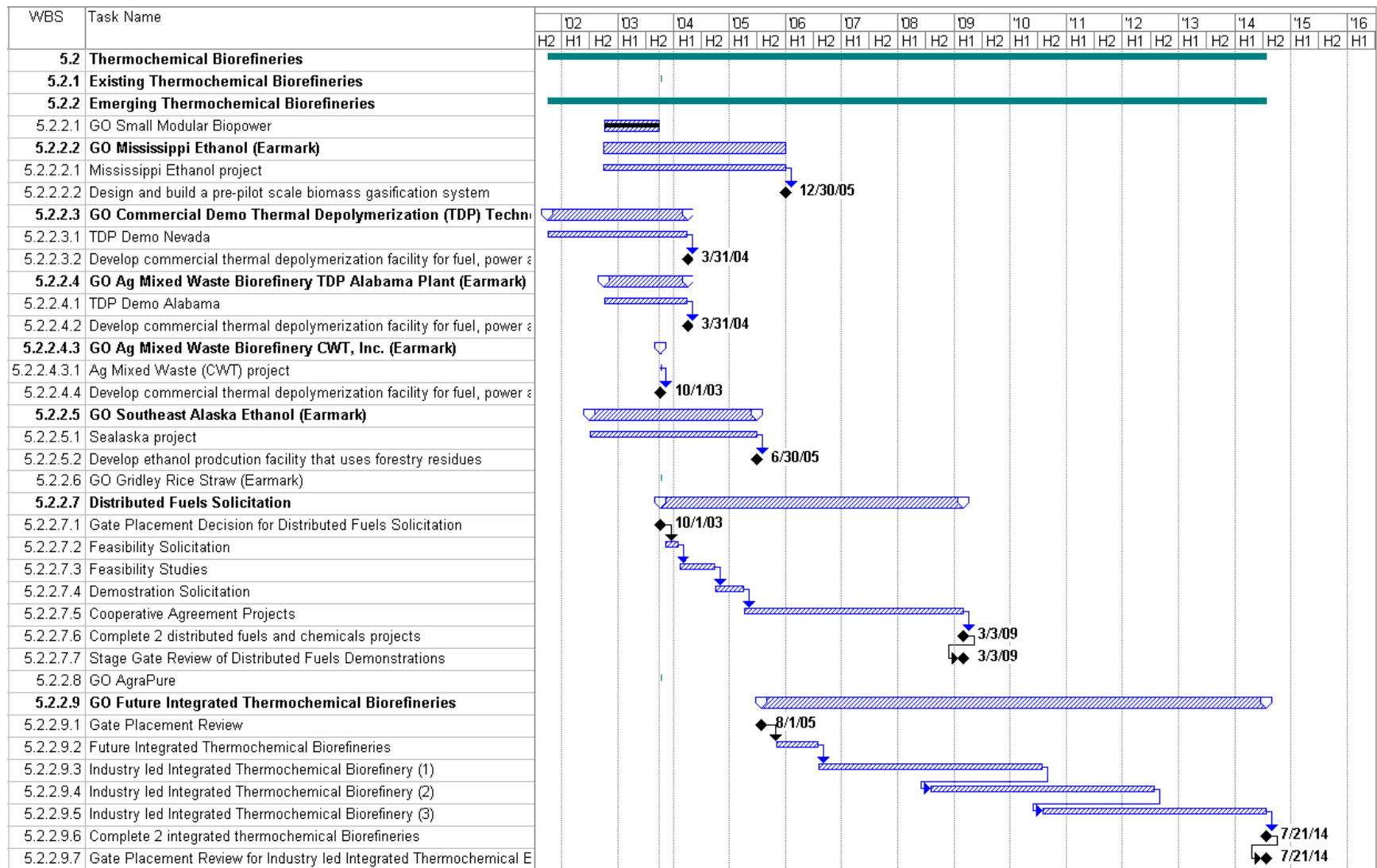


Figure 42: Biomass Program Industry Partnerships in Support of Integrated Thermochemical Biorefineries

Table 19: Resource Allocation Plan for Integrated Biorefineries

WBS	Title	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007
5	Integrated Biorefineries	\$7,256	\$19,767	\$64,522	\$50,535	\$45,380	\$37,304
5.1	Sugar Biorefineries	\$2,505	\$6,551	\$46,030	\$41,723	\$40,104	\$32,028
5.1.1	Existing Sugar Biorefineries	\$1,880	\$3,499	\$11,575	\$9,695	\$8,076	\$0
5.1.1.1	GO NCGA Products from Corn Fiber		\$1,619	\$1,619	\$1,619		
5.1.1.2	GO Broin			\$4,018	\$4,018	\$4,018	
5.1.1.3	GO IN Corn Dry Mill (Iriquois Bioenergy	\$1,880	\$1,880	\$1,880			
5.1.1.4	GO New Platform Intermediate (Cargill Dow, Codexis)			\$4,058	\$4,058	\$4,058	
5.1.2	Emerging Sugar Biorefineries	\$625	\$3,052	\$34,455	\$32,028	\$32,028	\$32,028
5.1.2.1	GO Abengoa			\$9,035	\$9,035	\$9,035	\$9,035
5.1.2.2	GO Integrated Corn Biorefinery (DuPont)			\$9,296	\$9,296	\$9,296	\$9,296
5.1.2.3	GO FIBEX Ethanol CoProducts, Biopolymers (MBI)		\$2,427	\$2,427			
5.1.2.4	GO Making Industrial Biorefining Happen!			\$13,005	\$13,005	\$13,005	\$13,005
5.1.2.5	GO Co-product Enhancement (Masada/Oxynol)	\$625	\$625				
5.1.2.6	GO Collection, Commercial Processing and Utilization of Corn Stover (Cargill Dow Polymers)			\$692	\$692	\$692	\$692
5.2	Thermochemical Biorefineries	\$4,751	\$12,246	\$17,522	\$7,842	\$5,276	\$5,276
5.2.1	Existing Thermochemical Biorefineries	\$-	\$-	\$-	\$-	\$-	\$-
5.2.1.1	NETL Big Island Demo Black Liquor						
5.2.1.2	NETL Black Liquor Gasification Support						
5.2.1.2.1	Causticizing for Black Liquor Gasifiers						
5.2.1.2.2	Direct Causticization for Black Liquor Gasification						
5.2.1.3	Advanced Gasif Fuel Conv and Elec for Forest Products						
5.2.2	Emerging Thermochemical Biorefineries	\$4,751	\$12,246	\$17,522	\$7,842	\$5,276	\$5,276
5.2.2.1	GO Small Modular Biopower						
5.2.2.2	GO Mississippi Ethanol (Earmark)		\$2,367	\$2,367	\$2,367		
5.2.2.3	GO Commercial Demo Thermal Depolymerization (TDP) Technology Nevada Plant (Earmark)	\$4,751	\$4,751	\$4,751			
5.2.2.4	GO Ag Mixed Waste Biorefinery TDP Alabama Plant (Earmark)		\$4,929	\$4,929			
5.2.2.5	GO Ag Mixed Waste Biorefinery CWT, Inc. (Earmark)			\$5,276	\$5,276	\$5,276	\$5,276
5.2.2.6	GO Southeast Alaska Ethanol (Earmark)		\$199	\$199	\$199		
5.2.2.7	GO Gridley Rice Straw (Earmark)						
5.2.2.8	GO AgraPure						
5.2.2.9	GO Distributed Fuels Solicitation						
5.2.2.10	GO Future Integrated Thermochemical Biorefineries						
5.3	Other Biorefineries		\$970	\$970	\$970		
5.3.1	GO Black Belt Demo		\$970	\$970	\$970		
5.4	Integrated Biorefinery Analysis						

Table 20: Alignment of Projects, Milestones and Technical Barriers for the Integrated Biorefineries Area

Biomass Program Goal: To support the establishment of integrated biorefineries through partnerships with industry and academia

Objectives:

- Complete analysis of biorefinery options by 2004 that identifies the most promising processes, products.
- Complete technology development necessary to enable start-up demonstration of a biorefinery producing fuels, chemicals and power by 2007.
- Demonstrate a fully integrated black liquor gasification system for heat and power production at a commercial pulp mill by 2009
- Help U.S. industry to establish the first large-scale sugar biorefinery based on agricultural residues by 2010.

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
Sugar Biorefineries GO	5.1.1.1 GO Separation of Corn Fiber and Conversion to Fuels and Chemicals Phase II: Pilot-Scale Operation (National Corn Growers Association)	<ul style="list-style-type: none"> • Develop and demonstrate an integrated biorefinery 	2/2004 Development of Process Economics 2/2004 Pilot Plant Site Selection 5/2004 Completion of Pilot Plant Design Package 2/2005 Completion of Construction/ Installation of Pilot Plant and Supporting Facilities 4/2005 Completion of System Start-up and Shakedown Testing 10/2005 Completion of Pilot Plant Operations Testing and Finalization of Flowsheet 5/2006 Final Assessment of Corn Fiber Process

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.1.1.2 GO A Second Generation Dry Mill Biorefinery (Broin)	<ul style="list-style-type: none"> Pretreatment, Processing, and Conversion 	12/2004 Detailed investigation 6/2003 Corn degerming and debranning design, construction and startup (PT) 9/2003 Bran pretreatment, conversion and fermentation (PT) 7/2204 Conversion of pretreated bran to ethanol and feed products (C) 12/2004 Conversion of bran to value added products (C) 12/2004 Preliminary economic evaluation of bran conversion (P)
	5.1.1.3 GO Indiana Corn Dry Mill Iroquois Bioenergy	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	Under Development
	5.1.1.4 GO New Platform Intermediate (Cargill, Codexis)	<ul style="list-style-type: none"> Products – Fermentation Products – Fermentation Products – Catalysis Products – Catalysis 	2/2006 Construct pathway and metabolic engineering for production of 3-HP 2/2006 Conduct pilot trials on the 3-HP fermentation process 2/2006 Demonstrate fermentation-derived 3-HP and its salts to acrylic acid and its salts, as well as to acrylamide 2/2006 Optimize catalyst for the conversion of fermentation-derived 3-HP to acrylic acid

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.1.2.1 GO Advanced Biorefining of Distiller's Grain and Corn Stover Blends: Pre-Commercialization of a Biomass-Derived Process Technology (Abengoa Bioenergy Corporation)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	11/2002 Complete Preliminary Mass Balance Analyses and Baseline Performance Evaluation 12/2002 Complete Technical Due Diligence 10/2003 Identify Enzyme Technologies to Develop Further Based on Potential Ethanol Yield 1/2004 Completion of Bench Scale Screening of Enzymes in ARBD's Proprietary Cook Process 2/2004 Complete Bench Scale Investigation of Process Improvements for Increasing Ethanol Yield 6/2003 Completion of Pilot Plant Design and Engineering 11/2004 Completion of Pilot Demonstration of High Ethanol Yield Corn Dry Mill Technology 3/2006 Pre-commercialization Demonstration of Step 1 Complete 12/2003 Complete Preliminary Feasibility Study of Pretreatment Options

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.1.2.2 GO Integrated Corn-Based Bio Refinery (ICBR) Project (DuPont)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery Pretreatment/Enzymatic Hydrolysis Products – Fermentation Develop and demonstrate an integrated biorefinery 	4/2004 Process Flowsheets/Economic Evaluation 4/2005 Test Process Concepts/Obtain Critical Data 4/2006 Process Develop & Optimization/ Cross-site Validations 3/2007 Rigorous Models/Large Scale Equipment Trials 4/2004 Scout Hydrolysis/Cellulase Screening and Discovery 4/2005 Pretreatment Process Develop/ Cellulase Discovery and Evolution 4/2006 Pretreatment Optimization/ Scale-Up 3/2007 Pretreatment Scale-Up/ Strain Development 4/2004 Benchmark Zymomonas mobilis, Xylose Utilization Genome Sequenced 4/2005 Rate/Yield/Titer/Tolerance Improved 4/2006 Rate/Yield/Titer/Tolerance Optimized on Hydrolyzate 3/2007 Fermentation Studies of Optimized Ethanologen 4/2004 Scout Syrup Grain Process 4/2005 Grain Syrup Development & Co-metabolism of Other Sugars 4/2006 Fermentation Studies of Optimized Ethanologen 3/2007 Scale-Up of Grain Process & 10L Fermentation Optimization
	5.1.2.3 FIBEX Ethanol GO Coproducts. Biopolymers, MBI (earmark)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	Under development

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.1.2.4 GO Making it Happen! (Cargill Dow)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery Pretreatment/Enzymatic Hydrolysis Products - Biocatalyst & Fermentation Technology Develop and demonstrate an integrated biorefinery 	1/2004 Confirm feasibility of biomass processing 7/2004 Complete pilot plant engineering 7/2005 Start-up pilot plant 8/2006 Validate commercial scale design in pilot plant 12/2006 Complete plant economics 3/2004 Develop metabolic engineering tools 1/2005 Develop 2nd generation strain for Xylose conversion 7/2006 Develop 3rd generation strain for biomass sugar conversion 12/2006 Select final strain meeting target performance 7/2004 Complete Alpha phase pilot fermentation 12/2006 Complete Beta phase pilot fermentation
	5.1.2.5 GO Co-Product Enhancement (Masada/Oxynol)	<ul style="list-style-type: none"> Process Integration 	Dates Being Revised 7/2001 Develop detailed test protocol 7/2001 Design hydrolysis system 11/2001 Equipment procurement installation 10/2001 Raw material procurement 11/2001 Biosolids processing 12/2001 Hydrolysis 12/2001 Filtration/lignin residue production 1/2002 Acid/sugar separation 2/2002 Neutralization/gypsum production 2/2002 Sugar concentration 2/2002 Acid concentration 2/2002 Hydrolysis with re-concentrated acid 3/2002 Fermentations 5/2002 Distillation/waste water production 6/2002 Wastewater treatment 6/2002 Evaluation/recommendation and implementation plan

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.1.2.6 GO Collection, Commercial Processing and Utilization of Corn Stover (Cargill Dow Polymers)	<ul style="list-style-type: none"> • Lack of robust feed preparation and handling systems. • Cost-effective collection and transport difficult due to low residue tons/acre. • Storage costs and risks due to short crop residue harvest window. • Consistency and quality of raw materials. • Impact of weather conditions on raw materials. • fire hazard of stored biomass. 	10/2004: Develop and test new technologies that harvest, transport, store, and separate corn stover to consistently supply clean, raw materials to downstream processors
Thermochemical Biorefineries NETL/GO	5.2.1.1 NETL Big Island Demonstration Project – Black Liquor		
	5.2.1.2 NETL Black Liquor Gasification Project		
	5.2.1.3 Advance Gasifier Fuel Conversion and Electricity for Forest Products		
	5.2.1.3.1 Cautisizing for Black Liquor Gasifiers		

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.2.1.3.2 Direct Cautisization for Black Liquor Gasification		
	5.2.2 Emerging Thermochemical Biorefineries		
	5.2.2.1 GO Small Modular Biopower		
	5.2.2.2 GO Mississippi Ethanol Gasification Project (Mississippi Ethanol, LLC) (Earmark)	<ul style="list-style-type: none"> • Products (syngas) process integration, syngas gas cleanup • Products (syngas) fermentation. 	12/2003 Complete Gasifier Pre-Pilot Unit (1/10th scale) construction, assembly and testing at MSU-DIAL 12/2003 Complete Gasifier Pilot Unit design and construction 9/204 Complete Gasifier Pilot Unit testing and product gas characterization 9/2004 Complete gas clean-up design, construction and testing at MSU-DIAL 9/2005 Optimize the selection and performance of appropriate fermenting organisms capable of producing ethanol from the ME gasification product gas
	5.2.2.3 GO Commercial Demonstration TDP Technology Plant – Nevada (Gas Technology Institute) (Earmark)	<ul style="list-style-type: none"> • Develop and demonstrate an integrated biorefinery 	22 mo from start Complete Engineering and Design 29 mo from start Complete Site Preparation 25 mo from start Complete Permitting/Legal 29 mo from start TDP Equipment Installed 42 mo from start Shakedown and Plant Operation

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.2.2.4 GO Agricultural Mixed Waste Biorefinery TDP - Alabama (Gas Technology Institute) (Earmark)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	9 mo from start Complete Engineering and Design 12 mo from start Complete Site Preparation 12 mo from start Complete Permitting/Legal 17 mo from start TDP Equipment Installed 24 mo from start Shakedown and Plant Operation
	5.2.2.5 GO Agricultural Mixed Waste Biorefinery – Colorado (Changing World Technologies) (Earmark)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	6 mo from start Complete Engineering and Design 12 mo from start Complete Site Preparation 12 mo from start Complete Permitting Activity 17 mo from start TDP Equipment Installed 24 mo from start Shakedown and Plant Operation
	5.2.2.6 GO Southeast Alaska Ethanol Sealaska (Earmark)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	Under development
	5.2.2.7 GO Gridley Rice Straw (City of Gridley, CA) (Earmark)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	Under development
	5.2.2.8 Distributed Fuels Solicitation		Under development

Technical Barrier Area	Project	Specific Barriers Addressed	Milestones
	5.2.2.9 GO AgraPure Mississippi Biomass Project (AgraPure)	<ul style="list-style-type: none"> Develop and demonstrate an integrated biorefinery 	Feedstocks assessment Processing options Product market identification Site requirements, location, acquisition Permitting Labor, management & operations requirements Equipment procurement and construction Financing requirements, sources, acquisition Economic analysis Business plan development
Other Biorefineries	5.3.1 GO Black Belt Bioenergy Demonstration Project (Earmark)	<ul style="list-style-type: none"> Develop and demonstrate an Integrated biorefinery 	9/2002 Market Analysis 11/2002 Agricultural Resource Analysis 2/2003 Site Analysis 3/2003 Energy and Infrastructure Analysis 5/2003 Technology Assessment 7/2003 Economic Impact Study 9/2003 Engineering and Design 9/2003 Contracts, Permits and Concessions 12/2003 Financial Strategy 12/2003 Workforce Development 2/2004 Project Management Plan
Integrated Biorefinery Analysis NBC			

3 Program Management

The OBP has the overall authority and responsibility for managing DOE research, development and demonstration activities relating to the use of renewable biomass for fuels, chemicals, materials, and power. The OBP will provide the overall strategy, policy, management, direction, and programmatic expertise necessary for a balanced program of research, development, testing, and evaluation that will catalyze the establishment of biomass technologies. Further, the OBP will build its investment portfolio based on detailed market and technology analysis, in collaboration with leaders and technology experts from industry, academia, and the national laboratories and in union with the other programs within EERE.

The key characteristics of the program management approach are:

- Structure that promotes clear lines of accountability and responsibility
- Cooperative partnerships to leverage the OBP investment
- Program integration functions that focus on overcoming barriers to success and identifying strategies to achieve success most efficiently
- Analysis used to support decision making throughout the Program
- Communication strategies and information resources that enable robust participation by all program stakeholders

3.1 Program Management Structure and Participants

The organizational structure providing R&D management for OBP is shown in Figure 5-1. The OBP is one of eleven programs residing within the Office of Energy Efficiency and Renewable Energy (EERE), and under the purview of the Assistant Secretary for EERE. Overall management responsibility and authority for the program resides with the OBP Program Manager, who reports directly to the EERE Deputy Assistant Secretary (DAS) for Technology Development. All personnel within the Office of the Biomass Program report directly to the Program Manager.

3.1.1 DOE Headquarters—Program Management

The OBP is responsible for the routine operations of the office, as well as formulating strategic and operational plans, justifying and allocating resources, establishing R&D and programmatic priorities and goals, and evaluating the performance of its programs. Management of the overall program includes consideration of the President's National Energy Policy, EERE's Strategic Plan and priorities, and the EERE Strategic Program Review.

OBP implements agency policies and procedures, and reports on progress and activities to senior DOE organizational management. The Multiyear Program Plan, this Multiyear Technical Plan, the Multiyear Analysis Plan, Annual Operating Plans and Communications Plans provide the program management framework.

The program is composed of five R&D elements or technology areas:

- Biomass Feedstock Interface R&D
- Sugar Platform
- Thermochemical Platform

- Products (including fuels, chemicals, materials, heat and electricity)
- Integrated Biorefineries

Program management includes program-wide activities such as planning, budgeting, execution, evaluation, technical integration, and analysis, as well as crosscutting activities such as Outreach, Education, and Partnerships

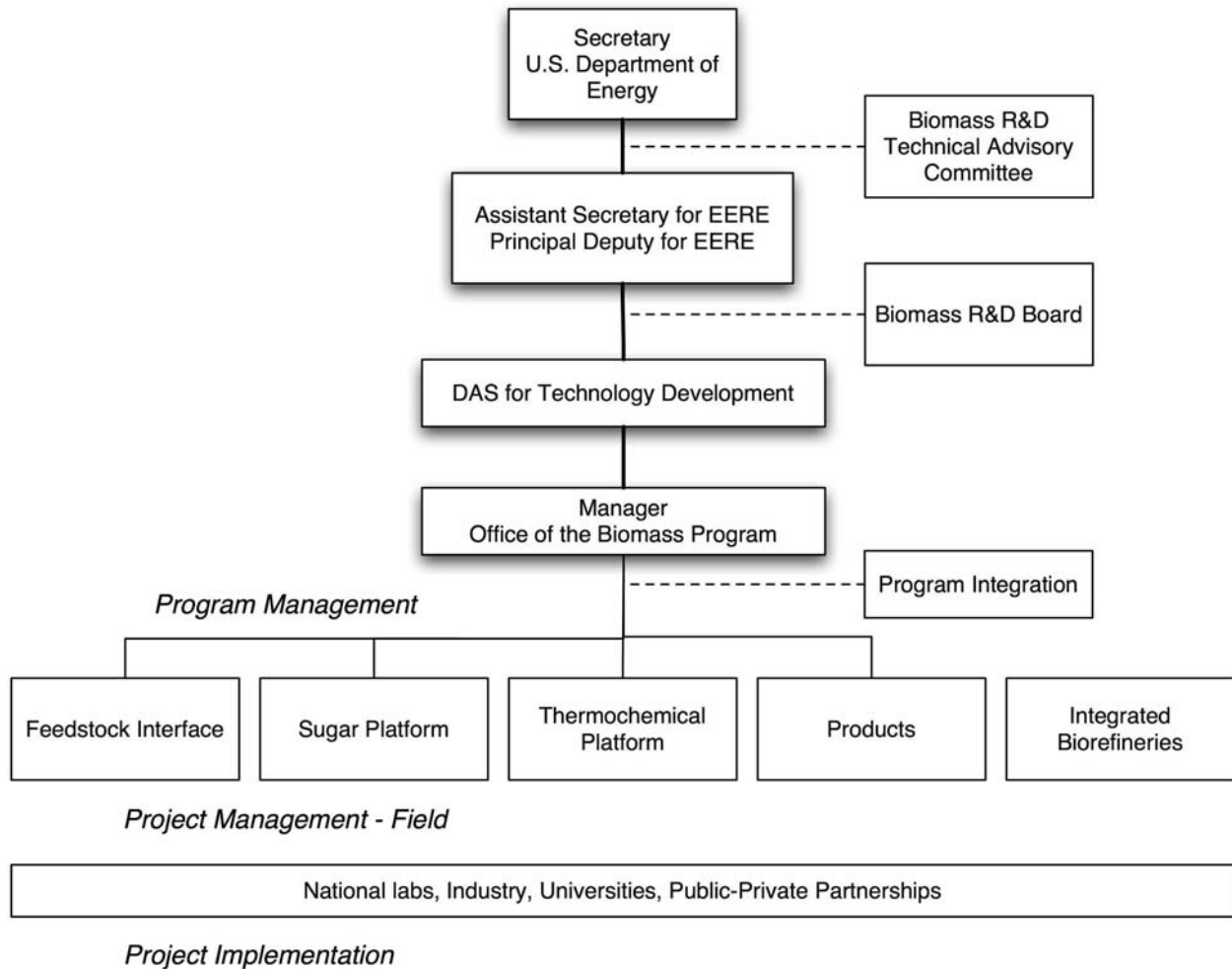


Figure 43: Organization Chart for the Office of the Biomass Program

The OBP organization fosters effective partnerships with its stakeholders in the public and private sectors. In keeping with the President’s Management Agenda, and the EERE Strategic Program Review, OBP has established a structure that focuses on program management and minimizes layers of authority, with the R&D goals as a centralizing theme. The respective capabilities of headquarters, field and operations offices, and national laboratories are utilized to optimize the strengths of these organizations and ensure the success of the program. The OBP has established teams that are responsible for management of technology RD&D and other administrative activities. Team leaders are responsible for keeping the program manager informed of successes and problems and formulating options to maintain progress and schedule.

3.1.2 Coordination with Other EERE Programs

Coordination with other program offices is essential for the success of the Biomass Program and EERE in total. Below are some specific examples of OBP's coordination efforts:

Hydrogen, Fuel Cells & Infrastructure Technologies Program - Biomass is one of the near term primary energy sources for hydrogen production. All of the work in biomass feedstocks interface R&D, the majority of the work on the thermochemical platform in gasification and pyrolysis, as well as some work in the sugar platform and products portions of the OBP portfolio directly supports the goals of the Hydrogen Program as well.

FreedomCAR and Vehicle Technologies Program - Research on the utilization of non-petroleum fuels, particularly renewable diesel and E-diesel, are coordinated and co-funded with the FreedomCAR and Vehicle Technologies Program.

Weatherization and Intergovernmental Programs -

- International - OBP provides technical assistance on international biomass related inquiries and projects.
- Tribal Energy - The Bureau of Indian Affairs is very interested in Small Modular Biopower applications on Indian reservations. Although this R&D effort is winding down, OBP will continue to coordinate tribal support activities through the Tribal Program staff.
- Clean Cities – The Clean Cities Program supports public-private partnerships that deploy alternative fuel vehicles and build supporting alternative fuel infrastructure. OBP cooperates with the Clean Cities Program by providing public documents in the Biomass Program's document database to the Alternative Fuels Data Center, which is the primary source of alternative fuels information for Clean Cities stakeholders.
- State Energy – OBP contributes to the State Energy Program (SEP) (See Section 3.5.3.1) and the State Technologies Advancement Collaborative (STAC) Program (see Section 3.5.3.4). RD&D awards from these programs for biofuels, biopower and bioproducts serve to augment the OBP portfolio.

Federal Energy Management Program – The Buy–Bio Initiative, supported by OBP, is implemented through the FEMP.

Office of Industrial Technologies – Biomass based technologies for fuels, chemical, materials, heat and electricity are of interest to the Chemical and Forest Products Industries of the Future.

EERE Communications Office – OBP's outreach efforts support and are coordinated with the broader corporate efforts managed by the EERE Communications Office.

EERE Business Administration, Planning, Budget Formulation and Analysis (PBFA)– OBP analysis activities are determined, in part, by the information needed by PBFA to carry out EERE cross-cutting corporate analysis.

Other DOE Offices – OBP collaborates with the Office of Science on basic science subjects such as plant biology, biotechnology, genomics, catalysis, molecular modeling, and nanotechnology. Office of Fossil Energy R&D on coal gasification and syngas utilization provide the basis for interaction with OBP.

3.1.3 DOE Field Offices – Project Management

The DOE Golden Field Office (GFO) supports EERE, including OBP, through field project management of R&D partnerships, laboratory contract administration, and a variety of professional, technical and administrative support functions. GFO is also accountable for funds expended under the NREL contract and for funds expended under grant programs administered through the EERE Regional Offices. The

National Energy Technology Laboratory (NETL) manages research projects on behalf of OBP in the areas of black liquor gasification and biomass gasification in the forest products industry.

Competitive solicitations are the primary vehicles for placing R&D partnership projects, although the national laboratories are funded directly for specific core research activities depending on technical capabilities.

3.1.4 National Bioenergy Center – Project Management and Implementation

The National Bioenergy Center (NBC) was established by DOE in 2000 as an inclusive center without walls unifying all of the resources at the National Laboratories of the DOE to advance technology for producing fuels, chemicals, materials, and power from biomass. The NBC provides technical assistance in areas of expertise, and is also responsible for managing core research activities of the Program. Collaborating with industry, academia, related EERE programs, and other government research, development, and commercialization efforts are central to these responsibilities. The preferred partnering mechanism between industry and DOE laboratories is the CRADA. The CRADA provides for intellectual property rights and patent waivers between DOE laboratories and industrial partners.

The NBC, under direct National Renewable Energy Laboratory (NREL) leadership, includes research and development supported by the OBP carried out at NREL, Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Idaho National Environmental and Energy Laboratory (INEEL), and Argonne National Laboratory (ANL). Tasks or program areas are assigned based on the capabilities and appropriateness of the organization for managing the work.

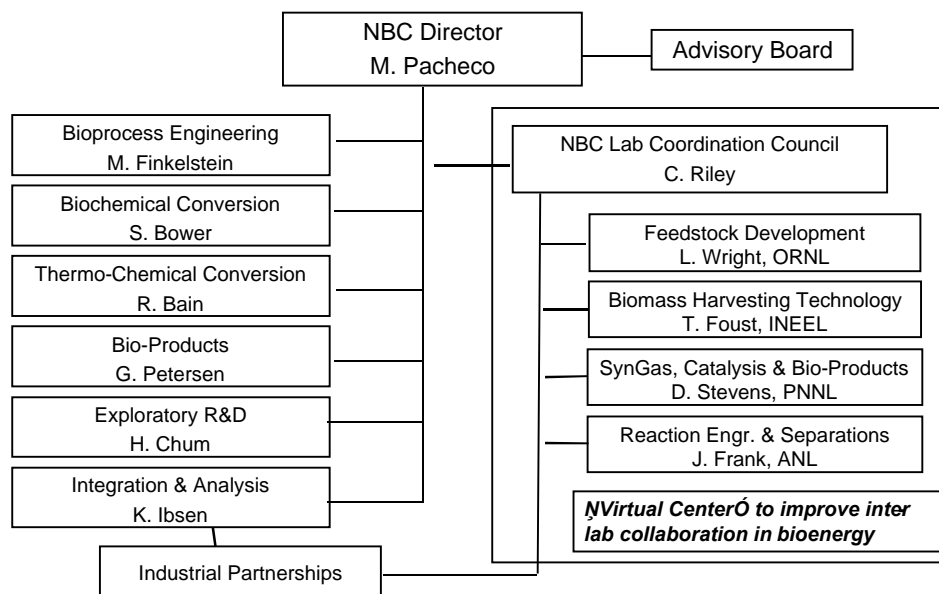


Figure 44: National Bioenergy Center Organizational Structure

3.1.5 Public Private Partnerships – Project Implementation

The Biomass Program is leveraging the vast capabilities and experience of its stakeholders through cooperative partnerships. The roles of stakeholder groups vary as do the nature of their collaboration with OBP. In broad terms the roles of these stakeholder groups are:

- Federal Agencies – Partnerships in research and development, environmental and regulatory issues, and coordinating biomass activities through the Biomass R&D Board. Of particular importance are partnerships between DOE/OBP and USDA.
- State and Local Governments – Partnerships in deployment, outreach, and education.
- Industry – Partnerships in research, development, validation and deployment of biomass technologies.
- Universities – Partnerships in research, analysis, and education
- International – Partnerships in research and development, outreach, and education.

3.1.5.1 Biomass R&D Board

The Biomass R&D Act of 2000 (Agricultural Risk Protection Act of 2000, Title III) created the Biomass R&D Board (the Board) that is responsible for coordinating biomass activities across Federal agencies. With its strategic planning, this cabinet level board seeks to guide the activities of various participating agencies in terms of Federal grants, loans, and assistance.

Membership includes the following agencies:

- U.S. Department of Agriculture (co-chair)
- Department of Energy (co-chair)
- National Science Foundation
- Environmental Protection Agency
- Department of Interior
- Office of Science and Technology Policy
- Office of the Federal Environmental Executive

Official functions of the Board include the following:

- Coordinating programs within and among departments and agencies of the Federal Government for the purpose of promoting the use of biobased industrial products by
 - maximizing the benefits deriving from Federal grants and assistance; and
 - bringing coherence to Federal strategic planning.
- Coordinating research and development activities relating to biobased industrial products--
 - between the Department of Agriculture and the Department of Energy; and
 - with other departments and agencies of the Federal Government; and
- Providing recommendations to the points of contact concerning administration of the Act.

Agency representatives to the Board for 2003 are:

Co-Chairs:

David K. Garman, Assistant Secretary, Energy Efficiency and Renewable Energy, DOE
Mark Rey, Under Secretary, Natural Resources and Environment, USDA

Members:

Bruce Hamilton, Director, Bioengineering and Environmental Systems Division, NSF
Jean-Mari Peltier, Counselor to the Administrator, EPA
Jim Tate, Science Advisor, DOI
Kathie Olsen, Associate Director for Science, OSTP
John Howard, Federal Environmental Executive, OFEE

The National Coordination Office serves as the executive secretariat for the Board, preparing reports and conducting the day-to-day activities to the Initiative. John Ferrell of OBP is the DOE co-chair of the National Coordination Office.

3.1.5.2 Biomass R&D Technical Advisory Committee

The Biomass Act of 2000 also created the Biomass R&D Technical Advisory Committee, an advisory group to the Secretaries of Energy and Agriculture. The Committee includes 30 industrial experts that advises DOE/OBP on its technical focus and reviews and evaluates proposals. The Committee also facilitates partnerships among Federal and State agencies, producers, consumers, the research community, and other interested groups. The committee created a “Vision for Bioenergy & Biobased Products in the United States” (October, 2002) and a “Roadmap for Biomass Technologies in the United States” (December, 2002). OBP has embraced the long range goals set in the vision document:

- 10 percent of transportation fuels will be biomass-derived by 2020.
- Biopower will meet 5 percent of total industrial and utility power demand in 2020.
- Biomass-derived chemicals and materials will account for 18 percent of the U.S. production of targeted chemicals in 2020.

The technical strategies and program goals of OBP, documented in this multi-year technical plan, have been designed to help meet these targets.

3.1.5.3 Collaboration with USDA

The Biomass R&D Act of 2000 directs the U. S. Departments of Energy and Agriculture to integrate technology R&D programs to foster a domestic bioindustry producing fuels, power and chemicals. OBP works closely with USDA in a number of ways. The technology base for products and energy within the USDA is provided by the USDA-Agriculture Research Service (ARS) through programs conducted at the five USDA Regional Agricultural Utilization Laboratories and their partners. Similarly, the USDA-Forest Service has the Forest Products laboratories to address use and resource conservation, including forest management. Scientific research on soil and water conservation is conducted by USDA soil conservation laboratories. Examples of DOE/OBP-USDA interagency collaborations include:

- Solicitations - The Biomass R&D Initiative within the Farm Bill authorized USDA to spend \$5M on bioenergy projects in FY02 and \$14M annually for FY 2003 - 2007. USDA selected projects from the biorefinery selections made by DOE for the initial funding. A joint solicitation was made in FY03 and more are planned for FY04 and beyond.
- Joint research - DOE laboratories, USDA Agricultural Research Centers and the Forest Products Laboratory are undertaking joint work under Interagency Agreements employing capabilities at each institution to accomplish biobased products, biofuels, or biopower research.
- Forest management - Stemming from a workshop on strategic federal laboratory partnerships, USDA is employing DOE/Industry-developed technology to assess the use of small modular biomass power systems to manage forest residues. The Forest Products Laboratory and DOE's National Bioenergy Center are jointly monitoring this work.

- Energy Audit and Renewable Energy Development Program for entities to administer energy audits and renewable energy development assessments for farmers, ranchers and rural small businesses (led by USDA Rural Development)
- Renewable Energy Systems and Energy Efficiency Improvements for loans, loan guarantees and grants to assist eligible farmers, ranchers and rural small businesses. (Led by USDA Rural Development/Rural Business-Cooperative Service).

3.1.5.4 State and Local Government

The OBP works with state and local governments and communities to integrate technologies and assess regional bioenergy opportunities. OBP also sponsors and participates in regional activities directed at expanding the bioindustry. Section 3.5.3 describes the specific State and Regional Partnership projects supported by OBP.

3.1.5.5 Industry

Partnerships with industry exist throughout the OBP portfolio with the Integrated Biorefinery portion made up exclusively of industry led projects. Industry stakeholders also participate in guiding and reviewing the program through membership on the Biomass R&D Advisory Committee, made up primarily of industry stakeholders, and as project gate-keepers in the stage gate management process. Industry groups are formally organized to provide input on key areas and gaps. For forest products, the American Forest and Paper Associations prepared the Agenda 2020 vision and technology roadmaps. The Biomass Interest Group, a consortia of electric utility companies and technology developers led by the Electric Power Research Institute, provides a mechanism for feedback and interactions among developers and users. The chemical industry is engaged via their Vision 2020 group and industrial roadmaps. Farm communities, their trade associations, and other interested industries are also engaged regularly.

Cost-shared RD&D is initiated via competitive solicitations is the preferred method of RD&D and technology transfer because U.S. industry is closely involved from a technical and planning standpoint as well as a financial standpoint (the cost-share). This involvement is by design and usually ensures a genuine effort by U.S. industry to commercialize the technology.

3.1.5.6 Universities

Universities provide a vital link to fundamental science and technology expertise. They also provide the critical foundation and setting for the development of a new set of engineers and scientists skilled in the disciplines necessary to build a bioindustry. A number of universities are partners in OBP activities, and participate via the same competitive mechanisms as industrial partners.

3.1.5.7 International

OBP cooperates with the International Program within the EERE Office of Weatherization and Intergovernmental Programs on biomass related activities and co-sponsors a World Biomass Conference with Canada and the European Union. International collaboration occurs through participation in International Energy Agency (IEA) activities related to biomass led by the IEA Bioenergy Committee. Doug Kaempf, Manager of OBP, represents the U.S. on the Executive Committee for IEA Bioenergy. Table 21 shows the IEA Bioenergy tasks currently supported by the U.S. The primary value of the IEA is in its information sharing activity. Typically the U.S. can access the fruits of other countries' RD&D programs long before they are distilled into reports and literature citations. Site visits offer great value in the area of lessons learned, which rarely if ever, reach the open literature. The activities conducted jointly provide an outstanding venue for discussion with foreign experts. The work program and task activities within IEA Bioenergy can be accessed from <http://www.ieabioenergy.com/IEABioenergy.php>.

Table 21: IEA Bioenergy Tasks supported by the U.S. (Federal organization providing support)

Task 30:	Short Rotation Crops for Bioenergy Systems (USDA-FS)
Task 31:	Conventional Forestry Systems for Sustainable Production of BioEnergy (USDA-FS)
Task 32:	Biomass Combustion and Co-firing (DOE-OBP)
Task 33:	Thermal Gasification of Biomass (Brigham Young University)
Task 34:	Pyrolysis of Biomass (DOE- HFCIT)
Task 35:	Techno-Economic Assessments for Bioenergy Applications (DOE-OBP)
Task 38:	Greenhouse Gas Balances of Biomass and Bioenergy Systems (DOE-OBP)
Task 39:	Liquid Biofuels (DOE-OBP)

There is also a biomass related activity under the Energy End-Use Technologies area, implementing agreement on Pulp and Paper: Annex XV - Gasification Technologies for Black Liquor and Biomass. This activity started with EERE's OIT and has major US involvements, managed through ORNL.

3.2 Program Management Approach

The work breakdown structure for Program Management, shown in Figure 45, translates the core activities of program management into a working organization of focused efforts and projects in three distinct areas:

- Program Management and Integration which includes program-wide activities such as planning, budgeting, execution tracking, evaluation, and technical integration.
- Analysis which includes analysis that cuts across the technical elements of the program and provides information to EERE/PBFA..
- Outreach, Education and Partnerships which are crosscutting support activities. Partnership activities included here are broad in nature with the goal of increasing collaboration with Regional, State and Local governments and encouraging the participation of small businesses in biomass related research through the Federal programs.

3.3 Program Management and Integration

The program will employ the four phases of the EERE management system:

- Planning
- Budget Formulation
- Budget Execution
- Analysis and Evaluation

The strategic plans of DOE and EERE are the foundation for the planning hierarchy for the Biomass Program. Figure 46 illustrates the timing of OBP management planning and evaluation activities throughout the year and grouped into two general categories:

- Program and portfolio management, and

- Project Management.

These activities are scheduled to coincide with Congressional budget schedules, fiscal year start-end, and internal DOE planning and project implementation factors.

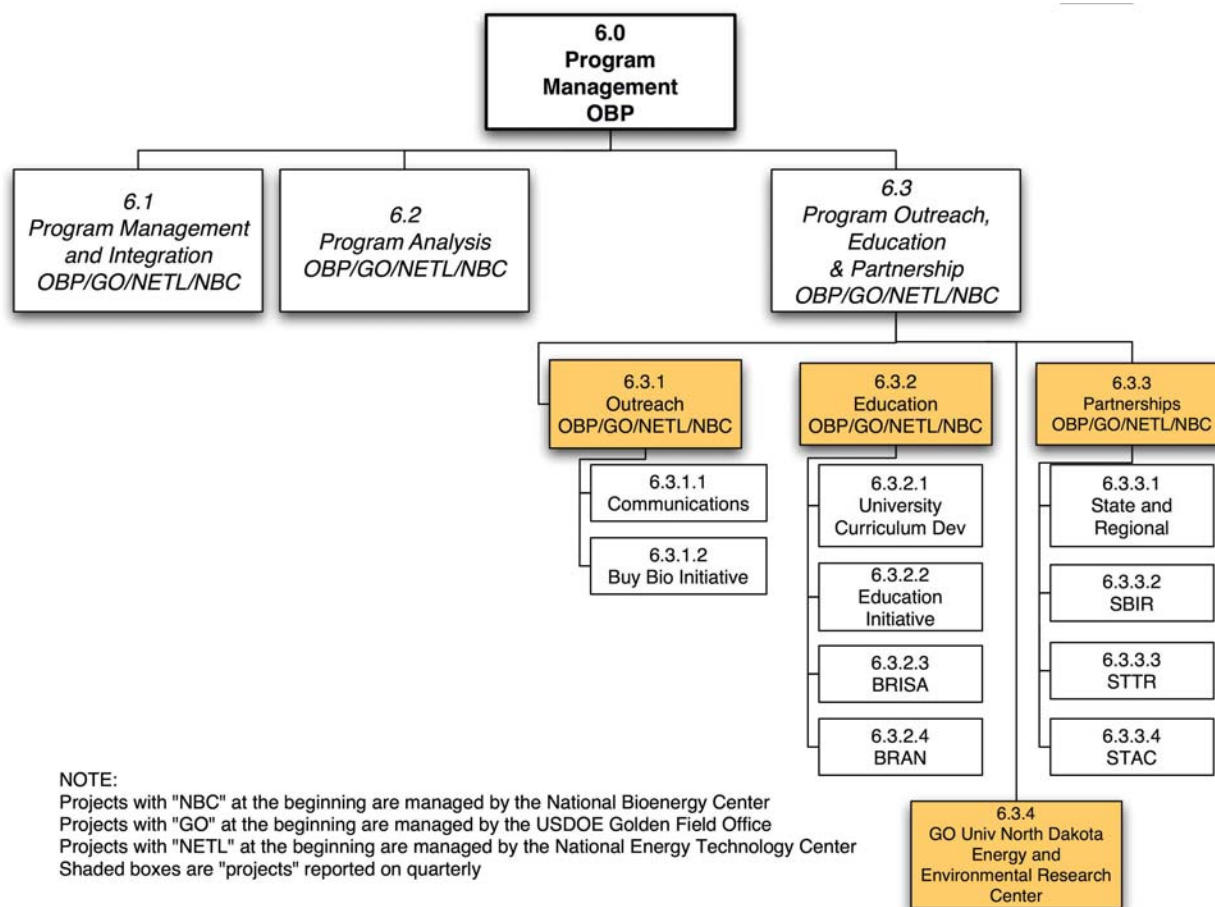


Figure 45: Work Breakdown Structure for Program Management

3.3.1.1 Program Planning

There are five OBP planning documents, included in the schematic shown in Figure 46 and described below, that guide and help to integrate the work of the OBP; the multiyear program plan (MYPP), the multiyear technical plan (MYTP), the multiyear analysis plan (MYAP), the annual operating plan (AOP), and the annual communications plan.

- The MYPP describes the OBP goals and strategies at a high level consistent with the DOE and EERE Strategic Plans.
- The MYTP is the link between the high level goals enumerated in the MYPP and the detailed plans for each project defined as part of the stage gate management process. By bringing together all of the separate plans that comprise the work of the program, the MYTP facilitates the identification of the linkages and interdependencies among the various projects being funded. The timing and duration of the activities included in the plan are resource driven. This is an

important feature of the plan that permits OBP to understand the relationship between the time required to meet the milestones and resources available to support them.

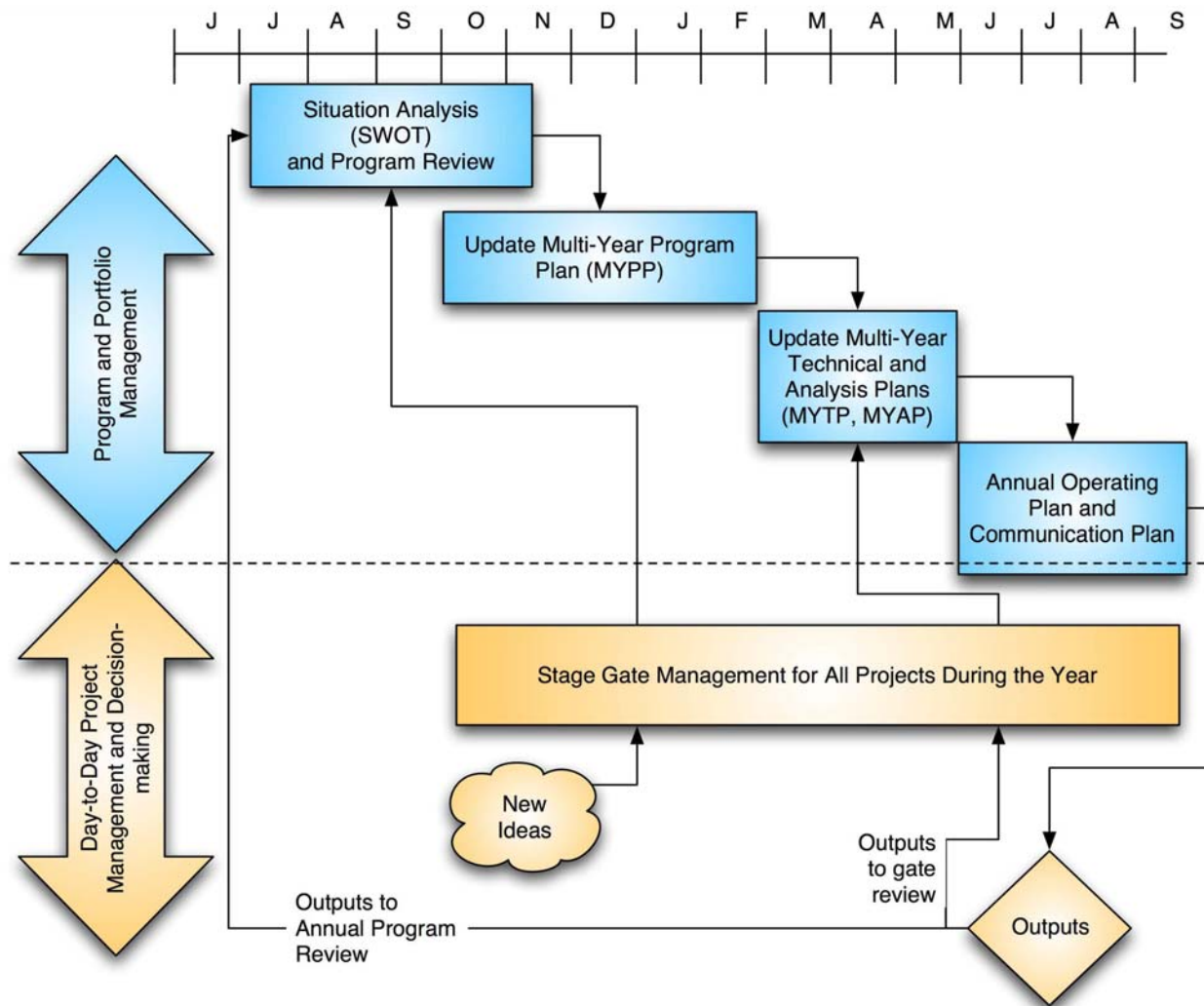


Figure 46: OBP Annual Planning, Control and Evaluation Schedule

- The MYAP is a multi-year plan showing the analysis activities needed to assess progress towards achieving OBP's goals. It will define tasks and resources for analysis efforts in feedstock development and infrastructure, technical and economic feasibility, environmental assessment, and the development of biorefineries and a bioindustry. Aimed at directing OBP funded analysis, this plan will include work by national labs, contractors, and Financial Assistance Awardees (FAA). The goals of the MYAP are to ensure that biomass utilization analysis efforts are credible, transparent, integrated and useful.
- The AOP is essentially a one-year slice of the MYTP and the MYAP. OBP has chosen to prepare a single all-inclusive AOP based on a compilation of the individual annual plans for specific technical projects and program support areas such as analysis. Each project plan includes objectives, a statement of work, milestones, schedule and cost projections along with specific performers of the research or support. These plans are the basis for evaluating performance during the year and identifying needed modifications during project execution. The milestones in

the AOP identify tangible, measurable results, against which actual achievement can be compared. Having a single AOP enhances overall program integration and communication.

- The OBP Communications Plan is updated annually. It describes the important OBP stakeholder audiences, identifies the specific activities planned for the upcoming fiscal year as they relate to those audiences, and provides up to date contact information for stakeholder groups and organizations.
- Stage gate management is a process employed at the project level to both plan the project and evaluate progress relative to the plan as the project moves along the technology development pathway. The decision making criteria employed are consistent with the OMB Applied R&D Investment Criteria, as described in the EERE Strategic Plan. Stage gate management is described in more detail in Section 3.3.1.4 below.

Control of planning documents is an integral part of the program management process. RD&D plans make assumptions that are sometimes market based and at other times are based on technology status. These assumptions change with time as both the technologies and market forces change. It is imperative to keep excellent documentation of the plans and the assumptions within the plans, and to track changes to the assumptions over time in order to keep the program focused and on the critical path. Program and technology development schedules emerge from the composite of plans described above, but only if they are well integrated and consistent. This is another factor that requires proper control of planning documents. This responsibility will reside within the program integration function, described in Section 3.3.2.

3.3.1.2 Program Budgeting

The budget falls under the jurisdiction of two separate Congressional appropriations subcommittees:

1. Energy and Water Development for Biomass and Biorefinery Systems R&D which includes
 - a. Advanced Biomass Technology R&D
 - i. Thermochemical conversion R&D
 - ii. Bioconversion R&D
 - b. Systems Integration and Production
 - i. Feedstock Infrastructure
 - ii. Bioconversion Production Integration
 - iii. Thermochemical Production Integration
 - iv. Crosscutting Biomass R&D

Activities under the Energy and Water Development funding have traditionally focused on developing advanced technologies for producing fuels and power using biomass feedstocks, or more specifically the work of the former Biomass Feedstock Development, Biofuels and Biopower Programs.

2. Interior and Related Agencies for Biomass and Biorefinery Systems R&D which includes:
 - a. Advanced Biomass Technology R&D
 - i. Thermochemical conversion R&D
 - ii. Bioconversion R&D
 - iii. Systems Integration and Production

iv. Technical Program Management Support

Activities under the Interior and Related Agencies funding have traditionally focused on developing advanced technologies for more energy efficient industrial processes and high-value industrial products, or more specifically:

- Products Development (formerly the Agriculture Industries of the Future), and
- Industrial Gasification (formerly the industrial gasification part of the Combustion Crosscutting Program and the gasification projects from the Forest Products Industry of the Future Program).

As a result of the EERE reorganization, the Program can better focus on research pathways for converting biomass into an optimized slate of useful outputs in an industrial biorefinery. As described in this plan, resources appropriated by both Energy and Water Development and Interior and Related Agencies are planned, executed and evaluated as one program.

3.3.1.3 Program Execution

As described in Section 2 of this plan, each project in the five program areas are discreetly identified and targeted to overcome specific barriers. Projects are carried out by industry contractors, national laboratories, and universities, or combinations thereof. Milestones have been established for every project to focus efforts on the performance targets. Within each area and project, activities are prioritized by assessing the current status against out-year targets. Since all related targets must be met simultaneously for a given technology development effort to be declared successful, trade-offs between related targets will occur and they cannot be evaluated separately. Based on the composite results from projects in a research area, the R&D may be re-focused and redirected. The Integrated Biorefinery portion of the program portfolio is ultimately where technology development efforts are integrated and validated in projects led by industry partners.

Milestone reports will be prepared to document completion of planned tasks. Results presented in these reports must provide project leaders, technology managers and program integration staff the information needed to robustly track the status of research efforts and measure progress toward program goals. Distribution of milestone reports will be determined on a case-by-case basis depending on the nature and sensitivity of the information included in a particular report. All program participants will strive to make information available to the widest audience.

Effective and timely internal communications are essential for an efficient organization. OBP has implemented a weekly highlights email process and two intranets, one for DOE only and one for DOE and the NBC to aid communication and collaboration among the program and project management participants. The intranets contain up to date program information including planning and management documents, presentations, a calendar, weekly highlights, and more.

OBP also supports the I-Manage and ePME efforts in DOE and the EERE plans to implement an interim corporate management system in FY04. OBP will provide all necessary management information to the system and may adapt or evolve management processes as necessary to accomplish this.

3.3.1.4 Program Analysis and Evaluation

Evaluation is conducted at the Program level and at the project level. Program reviews are carried out every two years according to EERE peer review guidelines. Members of the Biomass R&D Technical Advisory Committee are included as reviewers. This multi-year technical plan is currently undergoing such a peer review. In addition, the OBP has implemented quarterly and annual progress reports at both the project and program area levels. These reports provide information critical to successful program integration.

- Quarterly and annual progress reports are prepared for each technical project and support area outlining technical status, problems areas, achievements, and cost issues. Site reviews may be conducted as needed to assess obstacles and view the work in progress. This information is critical for the monitoring and controlling activities of project management.
- Project team leaders are responsible for preparing quarterly and annual summary reports that role up the collective status of each program area. This information is critical to conducting an overall program progress review at the end of each fiscal year.

At the project level stage gate management is the main process employed to analyze and evaluate progress in depth. Broadly it is a process for making disciplined, informed decisions about R, D&D investments that helps ensure program dollars are used effectively and efficiently. Stage gate management as practiced by the Biomass Program includes two paths, or tracks, that a project can take depending on the planned outcomes from the project. The commercial track is for projects where the outcome is a commercial process or product. The research track is for more basic and applied research. Figure 3 shows the stages for both the commercial and research paths. As a project passes from one stage to the next, it moves to a higher level of spending. Decisions are made at the end of each stage as to whether a project will pass through the “gate” to the next stage. The result is that projects with technical or market issues are weeded out earlier rather than later, and more funds are spent on projects with the greatest potential for success. Project decisions are based on evaluation of gate criteria including strategic fit, market risks and benefits, technical feasibility, competitive advantage, environmental risks and benefits, showstopper identification, and sound planning. Interim stage reviews are held at least on an annual basis for projects that are expected to be in a single stage for multiple years. A Stage Gate Management Guide has been prepared for the Biomass Program to inform and educate participants about the process and enable consistent and rigorous application throughout the Program. Information prepared for project gate reviews and interim stage reviews is another important source of technical information regarding project progress that is needed to perform the program integration function.

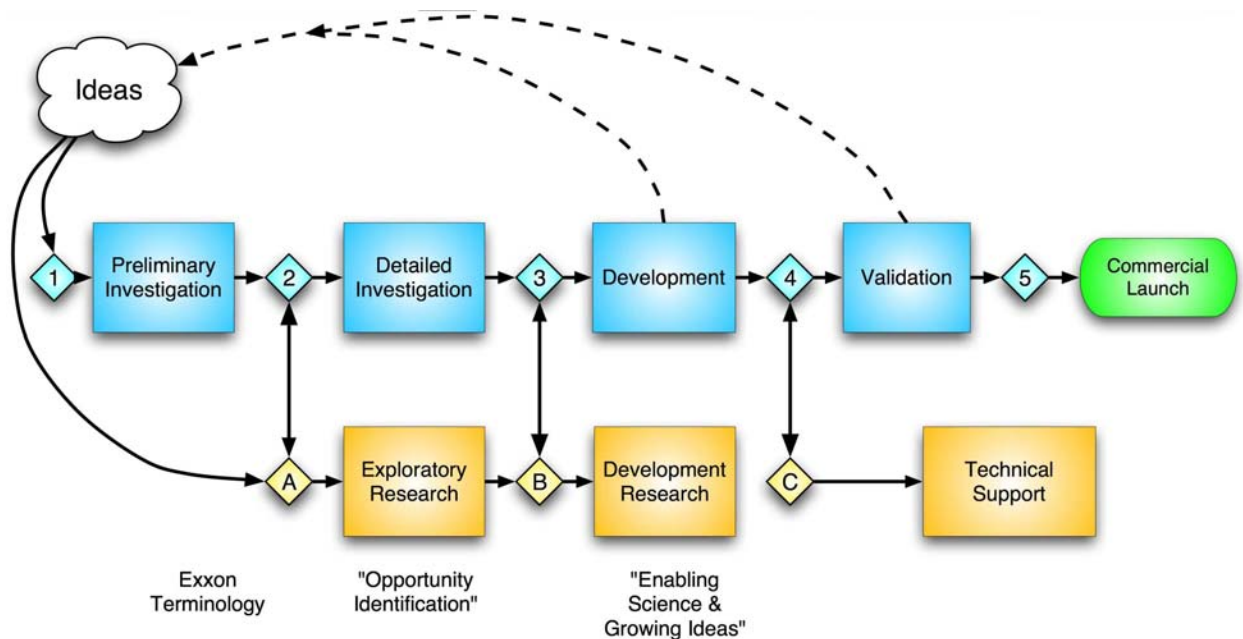


Figure 47: Stage Gate Management Flow Chart

3.3.2 Program Technical Integration

The OBP will implement a program integration function that provides and maintains a solid foundation for the results-driven program approach described above. The goal of this effort is to manage the complex interactions between interrelated technical and programmatic elements of the program so that program objectives can be met in the most cost effective manner through ongoing evaluation of performance, cost, schedule and risk. Because industry and the energy, chemicals and products markets they serve are ultimately the customers for OBP technologies, the program must manage its efforts in the context of a dynamic system in which requirements are established by the ever-changing marketplace.

The interdependencies of program activities in feedstock interface R&D, sugar platform, thermochemical platform, products, and integrated biorefineries, need to be understood and the interfaces managed in order to integrate and align efforts in the program areas and even on individual projects within the program areas. The core function of program integration is to establish, validate and maintain the integrated technical and programmatic baseline. In order to accomplish this, the program integrator needs to establish and implement management tools that enable gathering, developing and analyzing data and information across and between each of the levels, 2) conduct analyses, planning and evaluation, and 3) interpret the results in products that identify issues and opportunities and provide well analyzed options and recommendations. These products will provide a strong and credible basis for program management decisions.

The program integration function will be carried out by an independent group that can provide systems engineering, analysis, and integration support to the Office of the Biomass Program. The program integration group directly supports the OBP Program Manager and works in collaboration with OBP staff, GFO and NETL staff, and NBC staff at all laboratories. This group will assist OBP in strategic program planning, selecting program and policy options, formulating and justifying budgets and tracking program and projects progress against plans.

Key business integration functions include:

- Integrated field budget development, tracking, metrics, cost performance
- Procurement planning.
- Key technical integration functions include responsibility and accountability for:
- Technical planning – includes developing and maintaining the overall technical plans to achieve program goals (MYPP, MYTP, AOP)
- Technical information - includes tracking milestones, preparing quarterly program summary reports, and creating and maintaining data management systems.
- Technical Analysis and Evaluation – includes creation and maintenance of the integrated baseline that includes both a technical baseline and a program baseline. The technical baseline describes the performance requirements that must be met to achieve the goal(s) of the program. Analysis efforts throughout the program will contribute to the technical baseline. The program baseline contains information on the projected costs associated with each work element and the schedule interdependencies.
- Capability Development and Integration – includes identifying capability gaps and strategies for developing unique capabilities to achieve program objectives.

3.4 Analysis

The Biomass program uses engineering and analysis to support decision-making, show progress to goals and direct research activities. Integrated analysis activities provide cross-cutting, quantified information to the Biomass program to manage its research portfolio, and develops analysis methods and tools to

benefit all analysis efforts. Platform level analysis activities provide direction, focus, and support to the development and introduction of feedstock production, processing and use technologies. The majority of process engineering and analysis is performed as part of the research platforms; refer to the specific platform analysis projects for details.

Integrated analysis provides direction and focus to the overall research program by evaluating the technical, economic, environmental, and market aspects of biomass utilization via integrated pathways. This analysis also provides quantifiable measures of success towards OBP's goals and is a part of the multi-year analysis plan (MYAP) for OBP and its EERE analysis activities. Integrated analysis has three objectives: 1) to combine the results of platform analysis into biorefinery process designs, 2) to assess emerging technologies that are not currently part of a research platform but have potential to improve biomass utilization, and 3) to develop advanced methods, tools and partnerships to improve analysis value and efficiency. This evolving analysis infrastructure also supports platform analysis and industry-led projects.

Figure 48 shows the components of integrated analysis. Analysis philosophy represents the highest level assumptions and rules that an analysis will follow. The level of rigor is determined by the project stage and data available. The analysis team ensures that all the methods and parameters used in the different analysis methods are well documented, transparent, credible, and updated regularly to reflect the dynamic nature of a robust RD&D program.

Figure 49 shows the types of analyses that are used in the program, supported by the analysis infrastructure of methods, tools and analysts. Used in combination, these analyses provide a sound understanding of the program technologies. Each of these methodologies provides information and recommendations to the program. In general, each type of analysis builds on results from other areas in the analysis pyramid, to quantify the benefits, drawbacks, and risks of different biomass utilization scenarios. Results from each type of analysis method, used at the appropriate level of rigor, are used in the stage gate reviews of individual projects as described earlier. Each element of the analysis pyramid is described below.

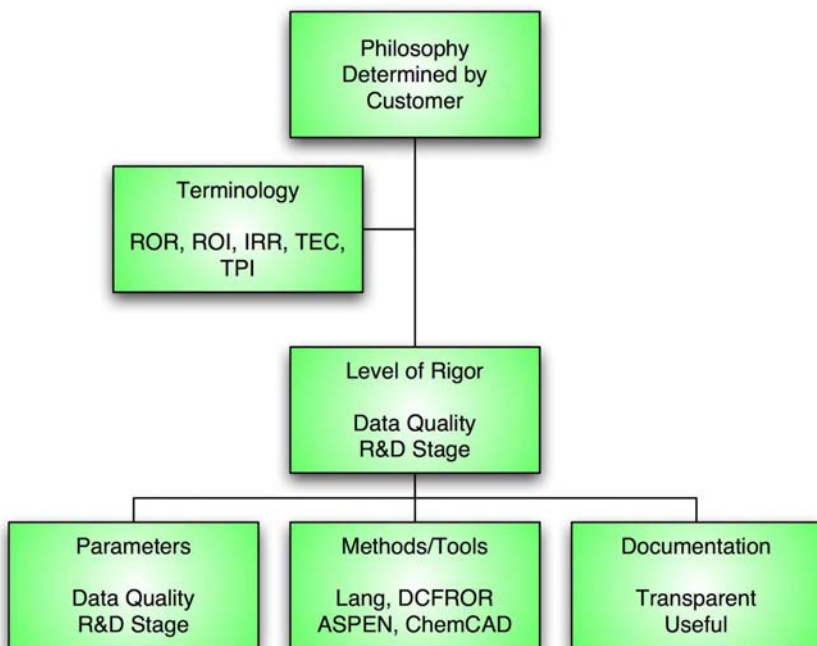


Figure 48: The Components of Integrated Analysis

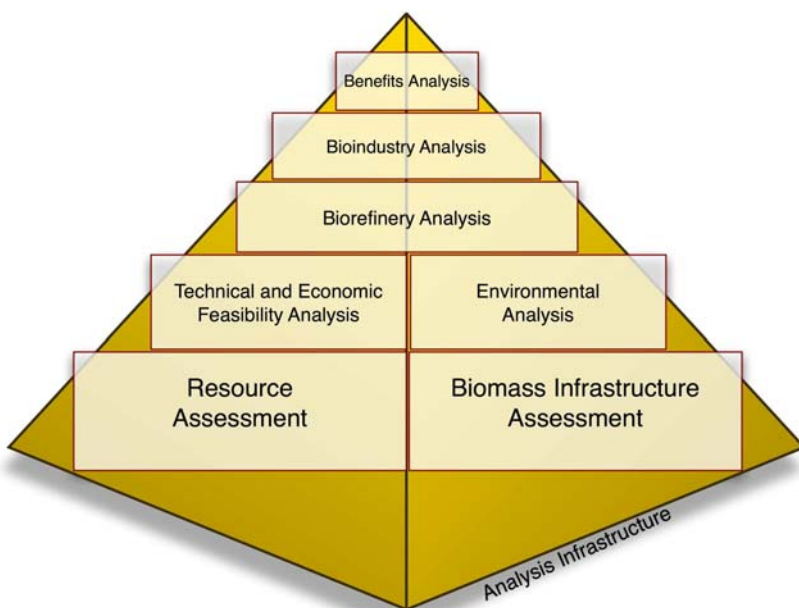


Figure 49: The Analysis Pyramid

3.4.1 Analysis Infrastructure

Analysis Infrastructure includes the resources (methods, tools, analysts) to perform the analysis for the Program. Maintaining these capabilities at the cutting edge is essential to ensure that the analysis provides most efficient and most complete answers to the technology developers and the program. Analysis methods for biomass processes are as new as the processes themselves. While some methods and tools from other industries (especially the process industries which includes petroleum refining and petrochemical processing) can be used with modification, others, like biomass physical property estimation methods, must be developed. Coordination, development of new methods, and communication are the three pieces to continuing to build the analysis infrastructure for biomass. Within the biomass scientific community, there is analysis at several levels with different methods. Developing partnerships in this community is key to ensuring the results are transparent, transferable and comparable. Building an analysis infrastructure for biomass R&D improves the analysis value and efficiency, while eliminating redundancy and gaps. Efforts by the NBC to combine the former biopower and biofuels analysis capabilities and methodologies, and align with the emerging Hydrogen Program analysis group are complete. The next step is to develop similar alignment between the national laboratories in the NBC and rest of the organizations performing R&D in support of OBP.

Multi-lab coordination plans include holding annual analysts' roundtable meetings, standardizing methods and developing web accessible tools, methods, data and documents. Near and mid-term new methods and tools development plans include training in the use of risk analysis for scientific processes, developing methods to track progress on all OBP projects, and continued pioneer plant analysis to understand first of a kind risks in plant costs and performance for stakeholders. Efforts to improve communication of analysis results to DOE and stakeholders include improved understanding of EERE analysis methods, tools and inputs, development of a multi-year analysis plan, and creation of technology design reports that are crucial to specifying the technology baseline and technical targets on a program wide basis.

3.4.2 Biomass Resource and Infrastructure Assessment

Resource assessment determines the quantity and location of biomass resources on state, county and land type levels. Additionally, resource analysis quantifies the cost of the resources, as a function of the amount that is available for utilization. An example of output from feedstock resource assessment is crop suitability for by geographic region of the US, shown in Figure 50.

Biomass infrastructure assessment identifies the optimal methods for collection, transportation and storage of biomass feedstocks, and much of this analysis takes place in the Feedstock Interface R&D program area. Since a robust biomass infrastructure does not exist, it is crucial to evaluate the many options for getting the biomass to the processing facility to determine which one(s) make sense in what areas. Developing a market basis for biomass is another part of the analysis, since biomass can be valued in several different ways. Combining the results of the Feedstock area analysis with those of the conversion platforms, sugar and thermochemical, allows synergies between the field and the processing facilities to be identified.

3.4.3 Technical and Economic Feasibility Analysis

Technical and economic feasibility analysis is performed to determine the potential economic viability of a process or technology, and helps to identify which technologies have the greatest likelihood of economic success. The biomass scientific community is continually developing technologies that could substantially improve the production of biomass intermediates and products. Initial assessment of emerging technologies and new ideas that are not currently part of the program portfolio but have potential to improve biomass utilization is performed to ensure biomass research stays at the cutting edge, reducing the time to commercialization and optimizing the DOE investment. A stage 1 level analysis is performed using available process and cost data and optimistic assumptions to create a best case scenario.

If the resulting scenario is feasible, then sensitivity analyses are performed to determine the cost sensitivity to process parameters such as yield. With the analysis results, the program can determine if the process should be added to the R&D portfolio. Results from technology feasibility analysis efforts provide input to decisions regarding portfolio development and technology validation plans. The economic competitiveness of a technology is assessed by evaluating its implementation costs for a given process compared to the costs incurred by current technology. These analyses are therefore useful in determining which projects have the highest potential for near-, mid-, and long-term success. Parameters studied include production volume benefits, economies of scale, process configuration, materials, and resource requirements. Tools used for technology feasibility analysis include process design and modeling (e.g., ASPEN Plus®), capital and operating cost determination, and cash flow analysis.

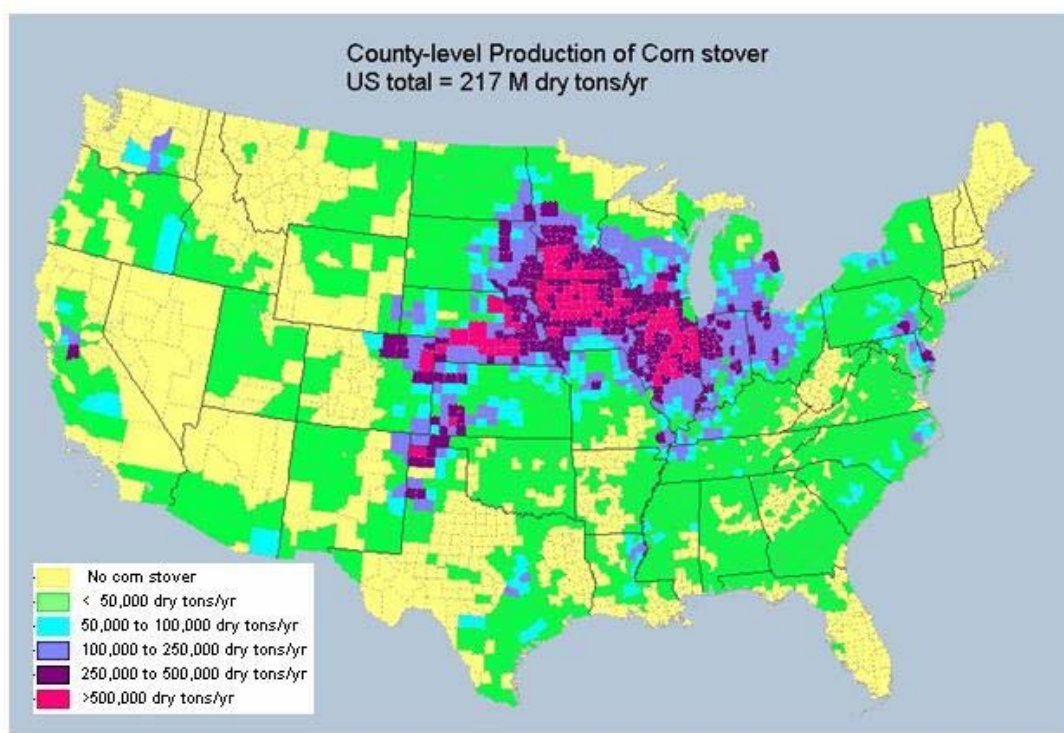


Figure 50: Corn Stover Production Map

3.4.4 Environmental Analysis

Environmental analysis is used by the Program to quantify the environmental impacts of biomass utilization technologies. Specifically, life cycle assessment is used to identify and evaluate the emissions, resource consumption, and energy use of all processes required to make the process of interest operate, including raw material extraction, transportation, processing, and final disposal of all products and by-products. Also known as cradle-to-grave or well-to-wheels analysis, the methodology is used to better understand the full impacts of existing and developing technologies, such that efforts can be focused on mitigating negative effects. Several detailed life cycle assessments have been carried out, documented

and peer reviewed on biomass to power and biomass to ethanol. Additional life cycle assessments will be carried out as needed to identify the important energy and environmental characteristics of new biomass-based processes.

3.4.5 Integrated Biorefinery Analysis

Integrated biorefinery analysis combines the technology assessments to determine the optimal mix of technologies to produce a slate of products. Utilizing a linear program type model, technology developers can study the possible options before investing in development or deployment activities. This “single biorefinery” optimization feeds directly into a “whole bio-industry” optimization in the market penetration analysis. With the integration of the former biopower and biofuels programs and the efforts in identifying candidate products from biomass, we now have the information in one place to develop emerging and advanced biorefinery process designs for plants producing a combination of power, fuels and chemicals. The Biomass program is currently working with existing biorefineries (dry mills, wet mills, pulp and paper mills, forest products facilities). A stage 1 analysis utilizing products with relative values based on a primary product (e.g. ethanol) will be performed first to understand the sensitivity of market value and size on the product slate. Then 4-5 emerging biorefinery process designs with integrated heat and power utilization will be developed, using the information from all platforms and the feedstock interface program. Mass and energy balances will be developed along with capital and operating cost estimates at a stage 2 level of analysis. Modules for syngas production and utilization will be added to BioRefine, a spreadsheet based linear program that currently contains sugar production modules. When new production technology designs (such as pyrolysis oil production) are completed in the platform analysis projects, they will be added to the biorefinery process design work and to BioRefine. Up to 4 model products will be selected to complete the process design from the products platform Top 10 analysis. The purpose of this selection is not to pick winners, but to find model products that will allow a complete analysis of the biorefinery process designs. From this process design, modeling and product optimization work, 1-2 possible pathways to a competitive biorefinery will be identified which can become the basis for designs in industry-led projects with the partner’s selection of products. The models developed as a part of this effort will be critical to evaluating options and opportunities relative to the program technology baseline characterizations.

3.4.6 Bioindustry Analysis

Bioindustry analysis determines market penetration for biorefinery products from multiple biorefineries. Scenario analyses, in the context of market analysis, are used to answer several questions:

- What are the feasible options for developing a future in which biomass plays a role?
- Which technologies are most likely to be a part of the biobased future, and what are the interactions between these technologies and other, established technologies?
- What market penetration pathways are likely?
- What are the scenarios for biomass use in energy, transportation and chemical markets?

3.4.7 Benefits Analysis

Benefits analysis helps the program quantify and communicate the overarching outcomes from biomass research, development and deployment such as imported oil displacement, miles driven on domestic fuels, and greenhouse gas mitigation, using EERE wide models such as NEMS and MARKAL. The scenarios that are developed and the costs and benefits that are quantified, are used to develop a broad understanding of the most viable routes for achieving biomass utilization. Results are useful in crosscutting benefits analysis, and are used in decision-making across all renewable technologies in the EERE portfolio. Additionally, all the analysis capabilities described in the analysis pyramid will be

synthesized into energy market analysis models to develop a broad capability for analyzing the development of possible biomass utilization. This is especially important in the area of environmental analysis, where renewable technologies are not well characterized. Also important in renewables benefits is a longer horizon analysis model. This work is performed by EERE/PBFA, and provides the intermediate and end outcomes for the EERE logic model, shown in Figure 51. Specific examples of the intermediate and end outcomes are shown in Figure 5.

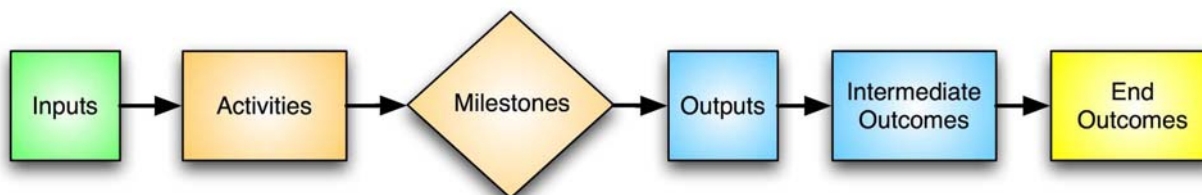


Figure 51: EERE Program Planning Logic Diagram

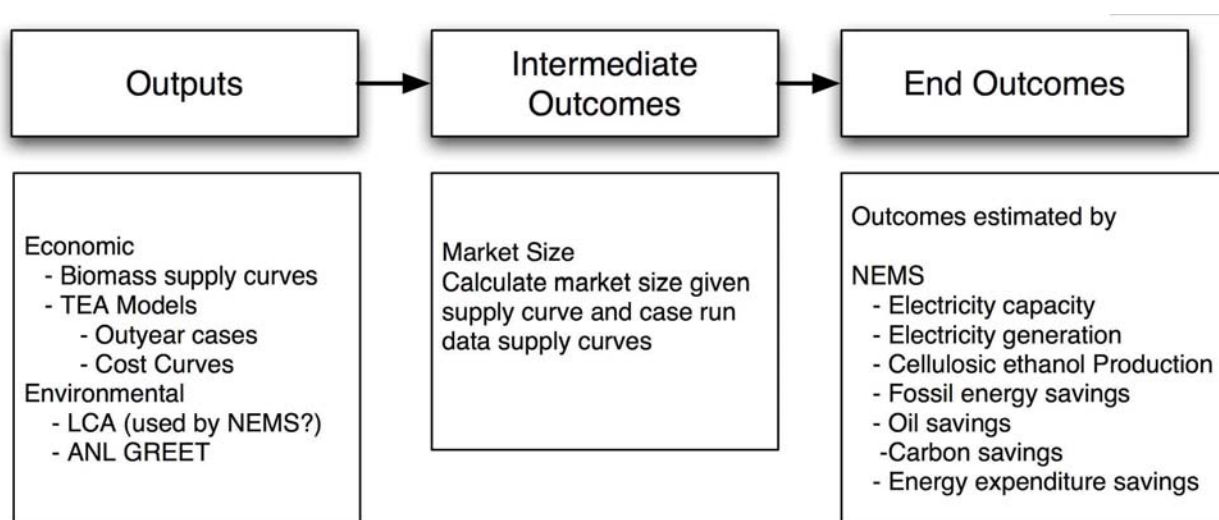


Figure 52: Sample Outputs from EERE Logic Model Steps

3.5 Outreach, Education, and Partnerships

This portion of the program management portfolio includes crosscutting activities in outreach, education and partnership development. Partnership activities included here are broad in nature with the goal of increasing collaboration with Regional, State and Local governments or organizations and encouraging the participation of small businesses in biomass related research through the Federal programs such as the Small Business Innovative Research Program.

OPB has a rich tradition of building partnerships to conduct joint research; to commercialize technologies and processes; to educate consumers and governmental agencies on the use of biomass-based fuels, chemical and products; and provide timely information and technology transfer assistance to potential users of biomass-based systems. These roles are expanding as interest grows in key audiences in biomass feedstocks, biomass conversion systems, and biobased products.

3.5.1 Outreach

The two major crosscutting outreach projects are Communications and the Buy-Bio Initiative.

3.5.1.1 Communications

To facilitate communications about program results and other OBP activities, the OBP annually develops a communications plan. This plan serves to guide outreach efforts and ensures that communications are effective and consistent. As with any new technology, people must become aware of it before they can choose to use it. Education and outreach are especially important for biomass because it offers significant economic and societal benefits (e.g., energy security, ambient air quality, and reduced GHG emissions) that are not fully represented in its price. Increased use of biomass relies on (1) recognition of the external benefits associated with bio-based options and (2) legislation (incentives and compliance). Both of these critical drivers hinge on successful education and outreach. DOE/OPB has identified a range of important audiences for its communications efforts, each with its own needs for information, its interests in biomass, and its own concerns. These key ten audiences that OPB has identified are:

- The Rural/Farm Community
- State, Local, Tribal, and Regional Organizations
- Business/Financial Community
- International Community
- DOE Senior Management
- USDA, and Other Federal Entities
- Industry
- Technology Developers/Users
- Academia
- Consumers.

OBP reaches out to these stakeholders by providing an array of communication products such as publications, a web site, workshops, conferences, and educational material. All of these products are designed to (1) engage industry in developing biomass technologies and practices, (2) stimulate manufacturer interest in applying those technologies and practices, and (3) encourage consumers to purchase biobased products.

OBP sponsors technical conferences and workshops on a variety of subjects to accelerate technology development and implementation. Examples are the Bioenergy series of regional conferences and the Biotechnology for Fuels and Chemicals Symposia (rotated yearly between Colorado and Tennessee and organized by NREL and ORNL). A number of regional and state activities are also sponsored. The Regional Offices have considerable activities devoted to information dissemination for EERE programs, including the OBP.

The OBP communicates technology development and other information to industry or customers through various outreach activities, including the Internet (<http://www.bioproducts-bioenergy.gov>) OBP's website provides information on new technologies, solicitations, publications, and legislative activities. It links with key USDA sites and other government and private sector activities, provides information on biomass activities sponsored by DOE, and characterizes the contribution of biomass to the economy.

3.5.1.2 Buy Bio Program

The U.S. federal government has the ability to demonstrate and foster new technologies and goods that provide energy-related, environmental, and economic benefits to the country. The Buy Bio Initiative was created in 2002 by the Departments of Energy and Agriculture to encourage federal procurement of one

category of such goods: biobased products such as ink, paint, construction materials, chemicals, lubricants, and plastics that are produced using domestically produced biomass feedstocks.

In the period FY04 – FY07, the DOE Buy Bio team and their counterparts at USDA will continue to work towards the goal of accelerating preferential purchases of biobased products in federal agencies through interagency work group coordination, performance monitoring, and recognition. One of Buy Bio's key priorities is to train procurement personnel, government credit card holders, and personnel involved with affirmative procurement to plan for biobased product purchases.

Iowa State University, under a cooperative agreement with the USDA Office of Energy Policy and New Uses, is developing the infrastructure to establish a biobased product testing program and to make available information on test results and other information. The efforts include a website that will be open to manufacturers/vendors to post information about their biobased products that qualify for preferred procurement under the statute. This information will be available to Federal agencies as they seek to identify qualifying biobased products to meet their procurement needs.

3.5.2 Education

In the “Roadmap for Biomass Technologies in the United States” the Biomass R&D Advisory Committee highlighted the need to develop science based education and outreach programs for K-12 as well as college and university levels. The first three projects described below are designed to help meet these needs. The forth project, the Biomass Rapid Analysis Network, is a response to requests from industry and university partners to develop rapid biomass chemical analysis methods along with a training program to educate researchers on their use.

3.5.2.1 University Curriculum Development

Providing a well-educated, well-trained workforce is critical for the commercial development of biomass technologies. This need is recognized in both the OBP Multiyear Program Plan, and the Roadmap for Bioenergy and Biobased Products. The goal of this education initiative is to provide a well-educated, well-trained workforce for the emerging biotechnology industry and for the expansion of the current biomass processing and biofuels industries.

To meet the need for a trained workforce, OBP has worked with eight Universities to provide students with knowledge, and experience in biomass processing and conversion technology. This work has involved engineers and scientists at both the undergraduate, and graduate levels. A number of new courses have been developed and the focus on many others has been broadened to include biomass related content. One project has resulted in the creation of an entirely new graduate degree in “Biorenewable Resources and Technology”. All of these projects were selected through competitive solicitations and will last three years.

3.5.2.2 Education Initiative – Mobile Learning Lab

In FY03, DOE/OPB launched an innovative program to take biomass feedstocks, conversion technologies, and processes to schools and universities through a mobile learning lab. This program will also seek to learn from the other outreach programs of other federal and state agencies and biomass stakeholders that are targeted toward high school and university audiences.

The initial years of this initiative will involve primarily background preparation and planning of the education initiatives in two focus areas – challenge competition and awards, and trailer based hands on demonstrations. The purpose of this preparative work will be to identify the best ongoing education activities in the federal government and different biomass stakeholder groups and in turn allow OBP to coordinate and leverage the best opportunities to build a sound program. In addition to overall planning, we will begin to set the stage for a Biomass to Energy “challenge” competition, modeled on the best aspects of the Solar Decathlon and JETS program for high school students and to put together several

demos for an ON the Road trailer where a viewer can clearly see the steps involved in going from biomass like corn, soybeans or crop residues to commercial/household-stage biobased products, fuels, and energy.

In selecting and developing the best activities for each focus area, DOE/OPB's overarching goal will be to have the educational activity 1) contribute to the broadest understanding and appreciation of how biomass derived products, fuels and energy have a positive impact on everyday life and 2) have the flexibility to reach the most meaningful populations/audiences for OBP's goals of building a biobased industry and contributing to our energy independence.

3.5.2.3 Biomass Research Initiative for Student Advancement (BRISA)

The BRISA Program (Biomass Research Initiative for Student Advancement) is a U.S. Department of Energy/Office of Biomass Program activity dedicated to providing Hispanic students and academic professionals research opportunities in the Biomass arena. BRISA was established to increase Hispanic student involvement and an eventual career path in the sciences and engineering. The program has been active since 1996 and has sponsored over 20 participants from the University of Puerto Rico and Colorado State University.

3.5.2.4 Biomass Rapid Analysis Network (BRAN)

Creation of the Biomass Rapid Analysis Network (BRAN) is a response to the request of industrial partners for biomass analysis methods that provide accurate, inexpensive biomass analysis at a speed relevant for process control. The BRAN is being developed as a network of industrial partners that join together to share the cost of calibration and validation of the many biomass analysis tools and methods needed by the emerging biomass conversion industry. The OBP will cost share the organization and start-up of the Biomass Rapid Analysis Network.

The BRAN approach is to develop new tools and analytical methods that can be used to monitor the composition of biomass feedstocks and biomass-derived materials throughout the biomass conversion process. In addition, a trained workforce is needed to conduct R&D, and standardized methodologies need to be developed so that commercial analytical laboratories can expand from the few currently capable of performing these analyses. BRAN will provide training materials and conduct training classes on the needed techniques and the QA/QC protocol established by the operation of the network.

3.5.3 Partnerships

One of the key characteristics of OBP's management strategy is to develop cooperative partnerships to leverage the OBP investment. Many of the specific research projects described in this MYTP are partnerships with industry, universities, other organizations or combinations thereof placed through competitive solicitations. The projects listed below also have the goal of creating partnerships, but generally on a broader and more crosscutting basis. The emphasis here is on State and Regional Partnerships and cooperative research and development with small businesses.

3.5.3.1 State and Regional Partnerships

DOE/OPB and its predecessor offices have had a long tradition of supporting regional biomass programs, as well as cooperative research, development and demonstration biomass projects with individual states.

The goals of the program for State and Regional Partnership activities include:

- Facilitate closer communication and encourage greater coordination among federal, regional and state biomass and bioenergy activities;

- Create awareness and support for bioenergy and biobased products and associated DOE programs at the highest levels of state government;
- Strengthen and maintain regional partnerships with other federal agencies, the states and stakeholders to help develop biomass as a potential and significant contribution to the Nation's energy portfolio
- Provide an effective communication conduit for states and DOE to identify and address biomass issues of mutual interest;
- Conduct activities supportive of DOE's Office of Biomass Programs and state goals that provide associated metrics that are acceptable to EERE

OBP's partnership efforts have two elements: regional and state energy office programs.

- The regional partnership program includes 5 Regional Host Organizations (RHOs) - the Council of Northeast Governors, the Council of Great Lakes Governors; The Southern States Energy Board, the Western Governors Association and the DOE Seattle Regional Office. Each RHO will provide leadership in their respective regions in addressing policies and technical issues in order to advance the use of biomass.
- The State Energy Program provides funding to states for the maintenance of State Energy Offices and undertaking state-specific energy conservation projects. Historically, SEP has provided funds on a competitive basis to designated Clean Cities coalitions for specific projects related to promoting alternative fuel vehicle (AFV) infrastructure development; acquiring AFV school buses; and acquiring commercially-available AFVs, particularly for niche market activities.

3.5.3.2 Small Business Innovative Research (SBIR) Program

Federal agencies with extramural R&D budgets over \$100 million are required to administer Small Business Innovative Research (SBIR) programs, using an annual set-aside of 2.5%. The SBIR program was created by the Small Business Innovation Development Act of 1982 (P.L. 97-219), reauthorized until September 30, 2000 by the Small Business Research and Development Enhancement Act (P.L. 102-564), and reauthorized again until September 30, 2008 by the Small Business Reauthorization Act of 2000 (P.L. 106-554).

The DOE SBIR program's budget for FY 2003 is expected to be about \$94 million, based on a set-aside of 2.5%. These funds are used to support an annual competition for Phase I awards of up to \$100,000 each for about 9 months to explore the feasibility of innovative concepts. Phase II is the principal research or R&D effort, and the awards are up to \$750,000 over a two-year period. DOE funds approximately 200 Phase I projects and about 90 Phase II projects per year. In Phase III, it is intended that non-Federal capital be used by the small business concern to pursue commercial applications of the R&D. Also under Phase III, Federal agencies may award non-SBIR funded follow-on grants or contracts for products or processes that meet the mission needs of those agencies, or for further research or R&D.

DOE's annual solicitation contains topics in technical areas such as: Basic Energy Sciences, Biological and Environmental Research, High Energy and Nuclear Physics, Fusion Energy Sciences, Advanced Scientific and Computational Research, Energy Efficiency and Renewable Energy, Nuclear Energy, Fossil Energy, Environmental Management, and Nonproliferation and National Security. Each year about 45 topics are allocated among the technical areas in proportion to their contributions to the budget. DOE plans to select for award those grant applications of the highest overall merit within their technical subject area.

To aid awardees in seeking follow-on funding for Phase III, DOE has sponsored a Commercialization Assistance Project for the past ten years which has provided individual assistance in developing business plans and in preparation of presentations to potential investment sponsors

3.5.3.3 Small Business Technology Transfer (STTR) Program

The program was created by Title II of the Small Business Research and Development Enhancement Act of 1992 (P.L. 102-564), reauthorized until the year 2001 by the Small Business Reauthorization Act of 1997 (P.L. 105-135), and reauthorized again until September 30, 2009, by the Small Business Technology Transfer Program Reauthorization Act of 2001 (P.L. 107-50). Federal agencies with extramural R&D budgets over \$1 billion are required to administer STTR programs using an annual set-aside of 0.15%. The set-aside will increase to 0.3 percent in FY 2004. The DOE STTR program's budget for FY 2003 is expected to be about \$5 million, used to support annual competitions among small businesses for Phase I and Phase II awards. Phase I explores the feasibility of innovative concepts with awards up to \$100,000 each for about 9 months. Phase II is the principal research or R&D effort, and awards are up to \$500,000 over a two-year period. This amount will increase to \$750,000 in FY 2004. There is also a Phase III, in which non-Federal capital can be used by the small business to pursue commercial applications of the R&D.

STTR is similar to the Small Business Innovation Research (SBIR) program in that both programs seek to increase the participation of small businesses in Federal R&D and to increase private sector commercialization of technology developed through Federal R&D. The unique feature of the STTR program is that, for both Phase I and Phase II projects, at least 40% of the work must be performed by the small business, and at least 30% of the work must be performed by a non-profit research institution. Such institutions include Federally-funded research and development centers (for example, DOE national laboratories), universities, non-profit hospitals, and other non-profits.

The DOE issues annual SBIR and STTR Program Solicitations. They are combined in one document, however, different rules apply to each program.

3.5.3.4 State Technologies Advancement Collaborative (STAC) Program

DOE, the National Association of State Energy Officials (NASEO), and the Association of State Energy Research and Technology Transfer Institutions (ASERTTI) signed an agreement on November 14, 2002, that allows States and Territories and the Federal Government to better collaborate on energy research, development, demonstration and deployment projects. The agreement established a five-year pilot program State Technologies Advanced Collaborative (STAC) that allows the States and DOE to move energy research, development, demonstration, and deployment forward using an innovative project selection and funding process. In addition, a STAC Operation Agreement was developed by the STAC Executive Committee to aid them in implementing this pilot project.

The State Technologies Advancement Collaborative (STAC) will promote research and deployment in innovative ways to produce, transmit and distribute energy and to use it more efficiently. The pact will make it easier for collaborative members to share information on research and to prevent wasteful duplication of efforts. By jointly funding selected projects, the Collaborative will be able to leverage funds and to simplify the path for promising technologies to enter the market.